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TECHNICAL MEMORANDUM

DETRIMENTAL EFFECTS OF HIGH SIDE LOBES IN A REVERBERATION FIELD (U)

Submitted to:
Commander, Naval Ship Systems Command
Washington, D. C.
Attn: Code 1631

May 5, 1967

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ABSTRACT

The AN/SQS-26 sonar system has been analyzed to determine at what level of element failure the combination of decreased signal strength and increased reverberation noise in the beamformer output causes a system failure to occur. A system failure criterion was established in terms of a decrease in the probability of signal detection, relative to a properly operating sonar. The probability of signal detection was related to the signal-to-noise ratio (S/N) in the beamformer output so that the failure criterion could be evaluated in terms of beamformer output S/N. The primary difference between this effort and previous efforts is that a noise field having reverberation characteristics, rather than an isotropic noise field, was used.

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1. INTRODUCTION

The purpose of this investigation was to determine the detrimental effects of high side lobes in the transmit and receive beam patterns of the AN/SQS-26 sonar system and to establish a criterion for determining when a system failure has occurred because of high side lobes.

The effect of high side lobes in an isotropic noise field was previously investigated and reported.[1] Therefore, the current effort was directed at determining the effects of high side lobes in a non-isotropic reverberation field.

Whenever failures occur in the transducer elements or associated electronics, changes in the beam pattern result. In many cases, these beam pattern changes represent decreased main lobe levels accompanied by increased side lobe levels. The decrease in the main lobe level results in a decrease in transmitted energy in the desired direction or a decrease in receiver sensitivity in the desired direction depending on whether the pattern is a transmit or receive pattern. The increase in side lobe levels can cause an increase in the reverberation intensity or an increased receiver sensitivity to the reverberation noise field. These two phenomena combine to produce decreases in the beamformer output signal-to-noise ratio (S/N).

---

[1] Tucker, E. A., G. T. Kemp, J. M. Young, W. A. Youngblood, "Some Redundancy Effects on AN/SQS-26 Performance(U)", TRACOR Inc., Tech. Memo. 63-233-C, Contract NObsr-89265, 9 Sept. 1963, (Confidential).

In this investigation, the approach was to assume failure of elements or individual channels in a random pattern across the face of the AN/SQS-26 array and to use an existing reverberation modeling program[2] to predict the change in signal-to-noise ratio which would occur at the beamformer output.

A failure criterion was adopted based on the change in probability of submarine detection which would occur as a result of element or channel failures. A previous report[3] contains charts from which may be obtained the change in probability of detection occurring with a change in beamformer output S/N at a constant clutter rate for the SQS-26 system. From these charts, it was determined that in most cases, a decrease in S/N of about 3.5 to 4 dB would cause the probability of detection to decrease from 0.75 to 0.25 at clutter rates of one mark per second or less. Therefore, a decrease in S/N of 3.7 dB was defined as the system failure level.

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[2] Fowler, Steve, "Bottom Bounce Reverberation Model and Bottom Loss Analysis (U)", TRACOR, Inc., Tech. Memo. 66-355-C, Contract NObsr-93140, 16 November 1966 (Confidential).

[3] TRACOR, Inc., "Analysis of Signal Processing and Related Topics Pertaining to the AN/SQS-26 Sonar Equipment (U)", TRACOR Doc. No. 65-336-C, Contract NObsr-93140, 11 October 1965, (Confidential).

2. FAILURE CRITERION

The major problem in declaring a system failure due to excessive side lobes is to determine a practical set of measurements that may be physically made aboard ship which will indicate that a side lobe failure condition exists. This study has developed a rationale by which a side lobe failure can be declared based on a knowledge of failures in the individual elements or associated electronics. Failures in the elements would be difficult to determine by shipboard measurements while underway. However, failures in the electronics associated with the elements could be determined through shipboard measurements.

The side lobe failure criterion was based on the decrease in the probability of signal detection which occurs with a loss of elements or associated electronics. A side lobe failure was defined as that electronic situation which would cause the probability of detecting a given target to be reduced from 0.75 to 0.25 in the presence of a reverberation noise field. Curves presented in a previous report[4] were used to relate the probability of detection to the S/N at the beamformer output for the SQS-26. Figures 2-1 through 2-4 show probability of signal detection versus signal-to-noise ratio for a linear correlator operating on FM slide signals with bandwidths of 30, 100, 200 and 400 Hz respectively.

Figures 2-1 through 2-4 show the probability of detection to be very sensitive to changes in the input S/N to the correlator. For example, for an FM slide signal with a 30 Hz bandwidth, a change in input signal-to-noise ratio of only 4.4 dB will cause the probability of detection to shift from 0.75 to 0.25 at a clutter rate of one mark per second.

[4] TRACOR, Inc. "Analysis of Signal Processing and Related Topics Pertaining to the AN/SQS-26 Sonar Equipment," op.cit. pp 74-77.

The change in S/N which is required to cause a change in the probability of detection from 0.75 to 0.25 is relatively insensitive to the clutter rate for clutter rates between one mark per second and one mark per ten seconds. Further, Figs. 2-1 through 2-4 show the required change in S/N to be relatively insensitive to changes in bandwidth. For example, with a 400 Hz FM slide pulse, an incremental change in S/N of 3.2 dB will cause the probability of detection to change from 0.75 to 0.25 as compared to 4.4 dB for the 30 Hz case.

This illustrates the important characteristic that although the absolute S/N required for a detection probability of 0.5 varies for different bandwidths and different clutter rates, in the region of 0.5, the variation of detection probability with changes in the S/N is relatively insensitive to changes in bandwidth, and is also insensitive to changes in clutter rates for clutter rates less than one mark per second. Therefore, as far as the signal processor is concerned, only one bandwidth and one clutter rate need be used to predict changes in detection probability as a function of changes in the beam pattern.

For this study, a bandwidth of 100 Hz and a clutter rate of one mark per second (Fig. 2-2) were used. The basic failure criterion used was that a 3.7 dB change in S/N will change the probability of signal detection from 0.75 to 0.25.

The signal-to-noise ratio for a properly operating beamformer was used as a reference. For cases simulating improper beamformer operation, changes in the peak response of the main beam were considered as denoting changes in the signal power level, and changes in the reverberation level were considered as denoting changes in the noise power level.

Some basic assumptions were made to determine an unacceptable change in the signal-to-noise ratio. These are shown in Table I.

TABLE I

SUMMARY OF ASSUMPTIONS AND STANDARD CONDITIONS

Assumptions:

1. The sonar system will be operated with a clutter rate of one mark/second or less.
2. If perturbing the array in some manner causes the S/N at the beamformer output to be reduced by 3.7 dB relative to the S/N from an unperturbed array beamformer a side lobe system failure will be declared.

Standard Conditions:

1. Wind speeds of 4, 12, and 20 knots.
2. Depths of 6,230, 7,550, 13,300 and 16,400 ft.
3. Constant bottom loss = 15.5 dB (i.e., independent of grazing angle).
4. Propagation loss = 2.16×10^{-4} dB/yd.

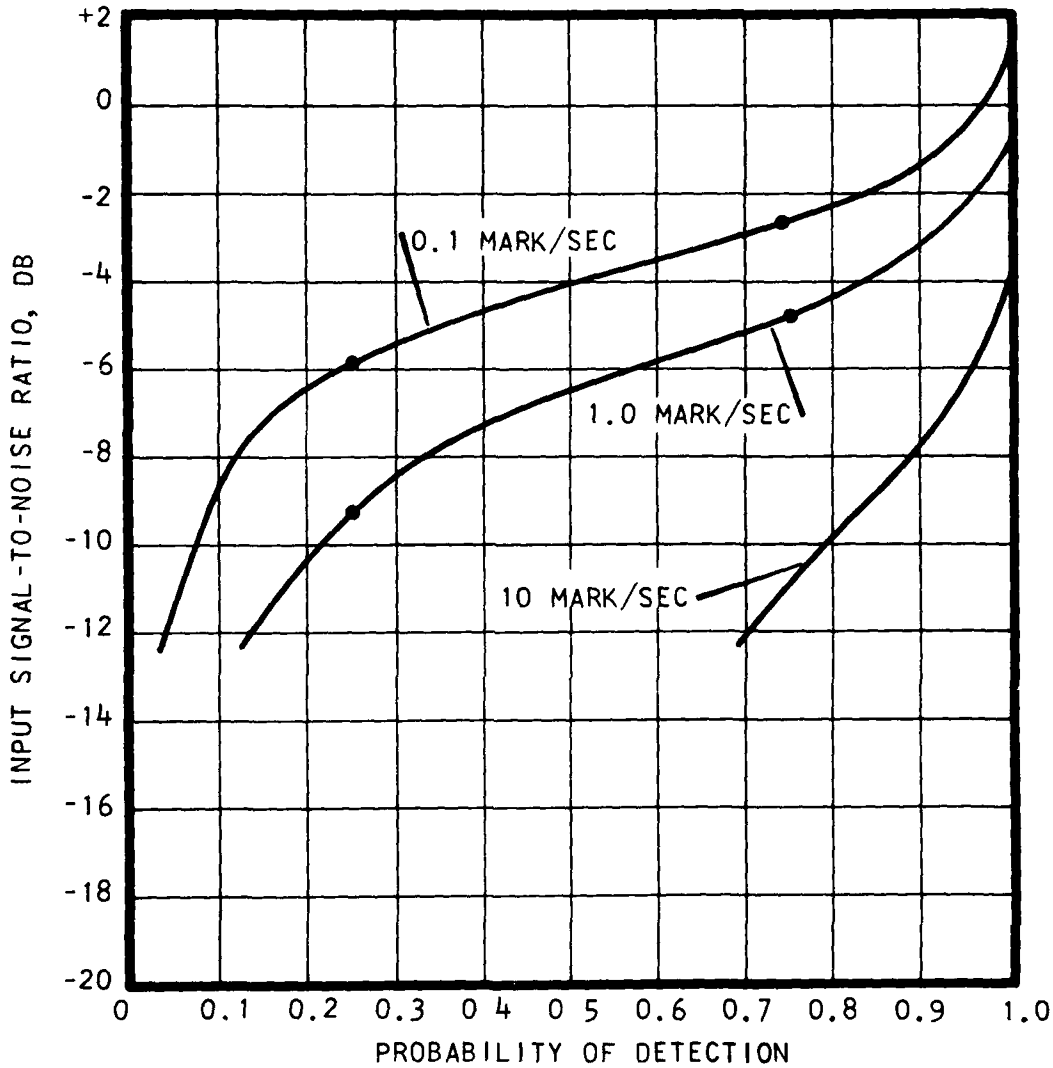

FIG 2-1 - PROBABILITY OF DETECTION VS REQUIRED INPUT SIGNAL-TO-NOISE RATIO WITH RATE OF EXCEEDING THRESHOLD AS A PARAMETER (LINEAR FM SLIDE SIGNAL WITH 30 CPS BANDWIDTH)

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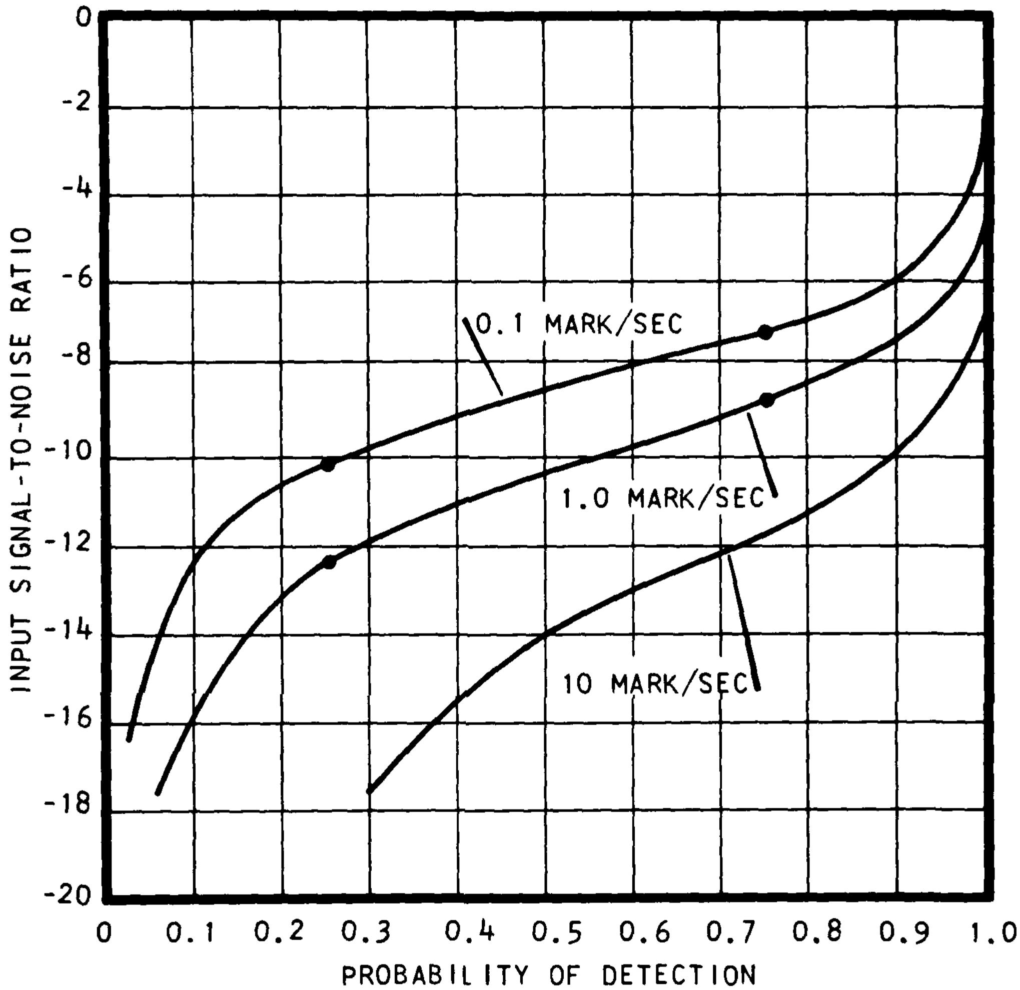

FIG. 2-2 - PROBABILITY OF DETECTION VS REQUIRED INPUT SIGNAL-TO-NOISE RATIO WITH RATE OF EXCEEDING THRESHOLD AS A PARAMETER (LINEAR FM SLIDE SIGNAL WITH 100 CPS BANDWIDTH)

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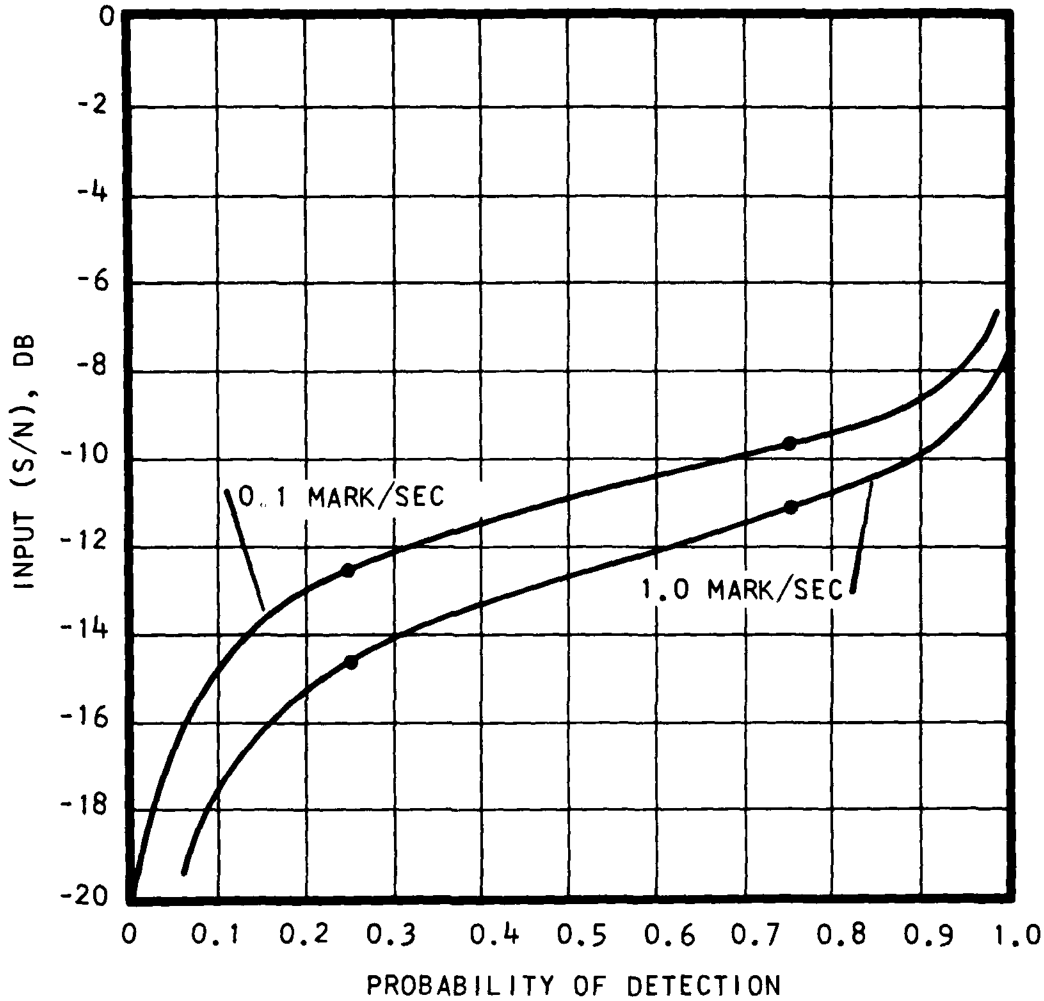

FIG. 2-3 - PROBABILITY OF DETECTION VS REQUIRED INPUT SIGNAL-TO-NOISE RATIO WITH RATE OF EXCEEDING THRESHOLD AS A PARAMETER (LINEAR FM SLIDE SIGNAL WITH 200 CPS BANDWIDTH)

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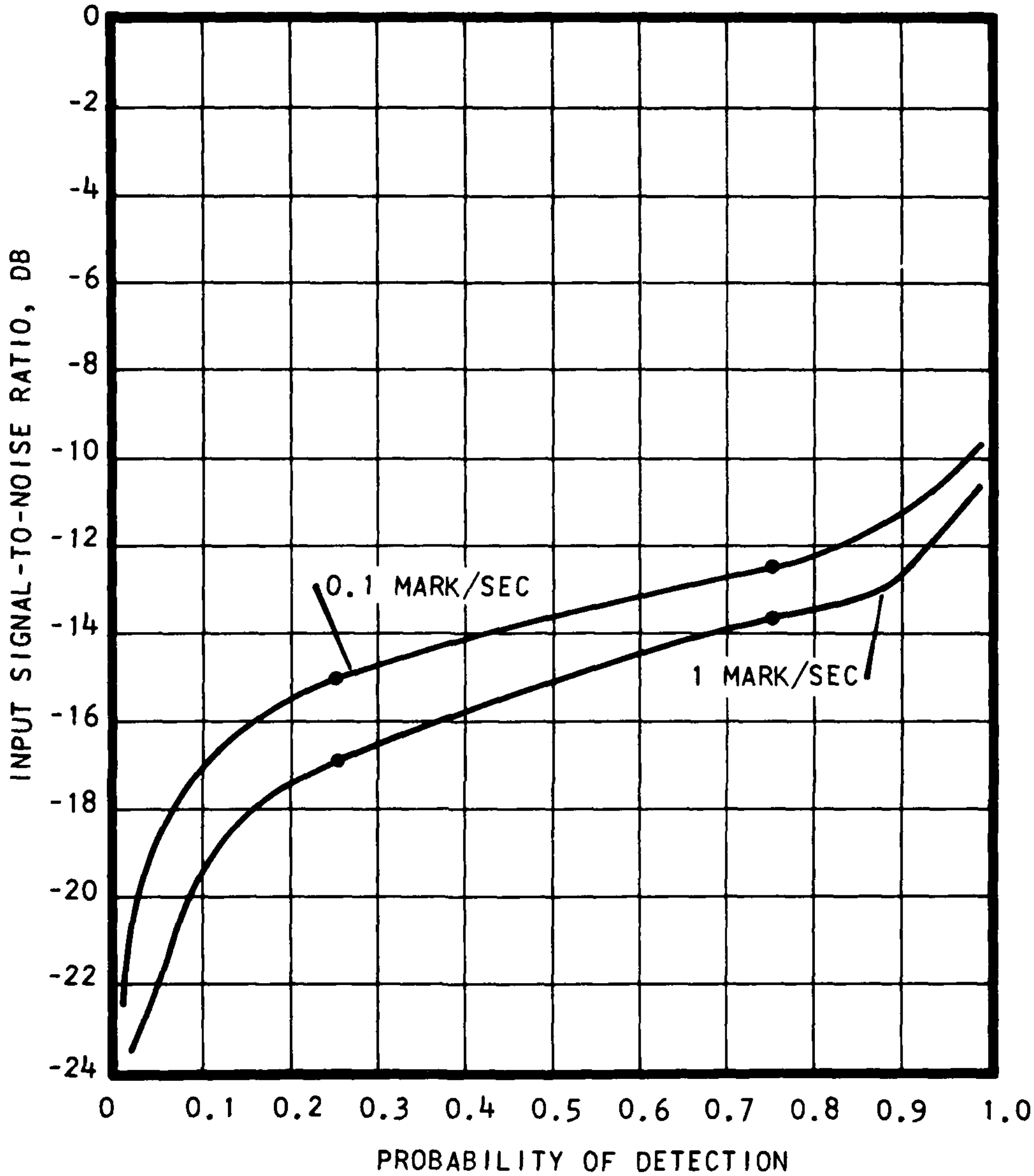

FIG. 2-4 - PROBABILITY OF DETECTION VS INPUT SIGNAL-TO-NOISE RATIO WITH RATE OF EXCEEDING THRESHOLD AS A PARAMETER (LINEAR FM SLIDE SIGNAL WITH 400 CPS BANDWIDTH)

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3. COMPUTATIONAL APPROACH

The three-dimensional beam patterns were computed by means of the procedure outlined in Appendix A. To insure that the proper source level would be obtained when operating with element failures, the patterns were normalized to the maximum of that particular pattern when all elements were operating properly. Figures 3-1 and 3-2 present contour plots of a 20° depressed receive beam pattern with all elements operating properly, and a 20° depressed receive pattern with 31.8% of the elements inoperative. These figures were obtained from the printed contour plots as presented in Appendix A.

The beam patterns were used as inputs to the reverberation model program. The reverberation model program also required velocity profile, wind speed, bottom loss, and propagation loss (Section 2, Table I). A detailed description of the model appears in a previous report[5]. The total reverberation level as a function of time after transmission with receive position, wind speed, depression angle, and depth as parameters was obtained. Figure 3-3 shows the total reverberation level for a wind speed of 4 knots, depth of 7550 feet, and depression angle of 20°. Graphs for other conditions appear in Appendix B.

The problem of declaring a system failure required determining a change in the signal-to-noise ratio. The signal level decrease in dB was considered as the sum of (1) the difference in the transmit pattern in the proper direction under normal operation and under operation with element failures, and (2) the difference in the main lobe response of the receive beam under normal operation and under operation with element failures.

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[5] Fowler, Steve, op.cit.

The noise level change in dB was found by subtracting the reverberation level under normal operation from the level computed with elements inoperative. The decrease in (S/N) in dB was then found by adding the signal level decrease to the change in reverberation level. Figure 3-3 shows the decrease in (S/N) as a function of time after transmission for a wind speed of 4 knots and a depth of 7550 ft at five receive positions. The decrease in (S/N) was averaged over the five receive positions in order to determine the average change in (S/N). (See Section 4, Figs. 4-1 and 4-2). The relative locations of the transmit and receive positions are shown in Appendix B, Fig. B-1. A system failure was declared if the average (S/N) decrease was 3.7 dB or greater.

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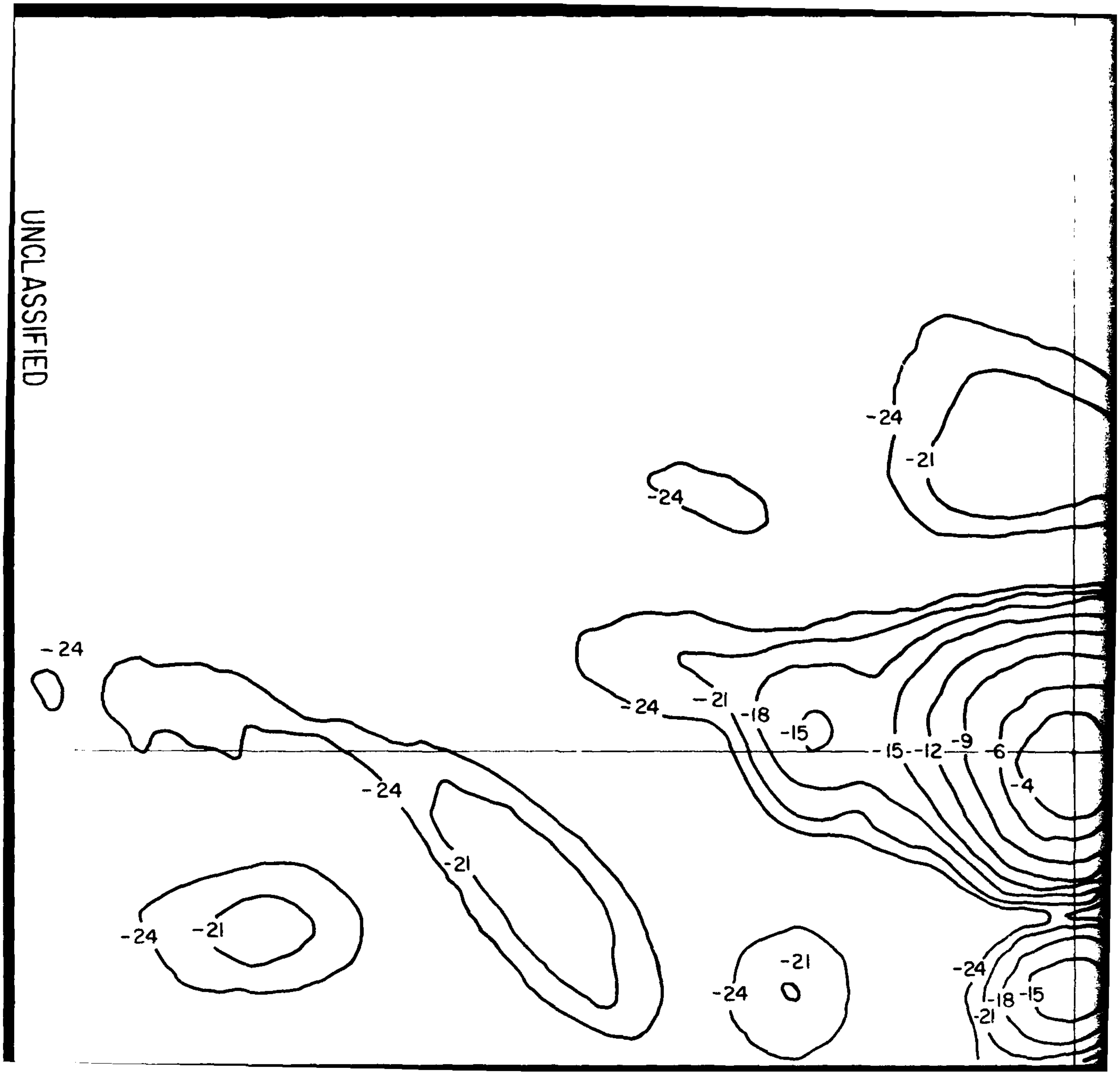

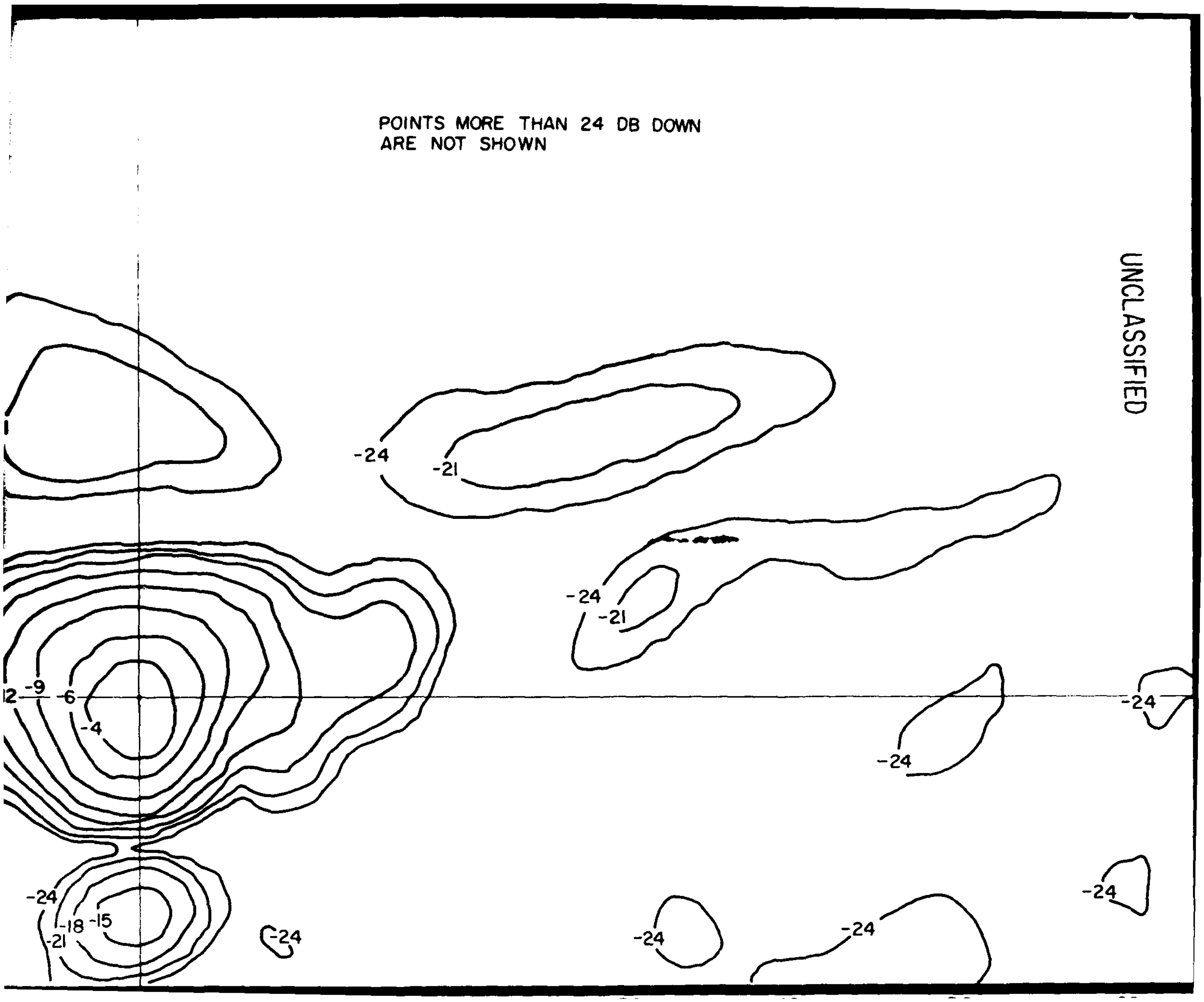

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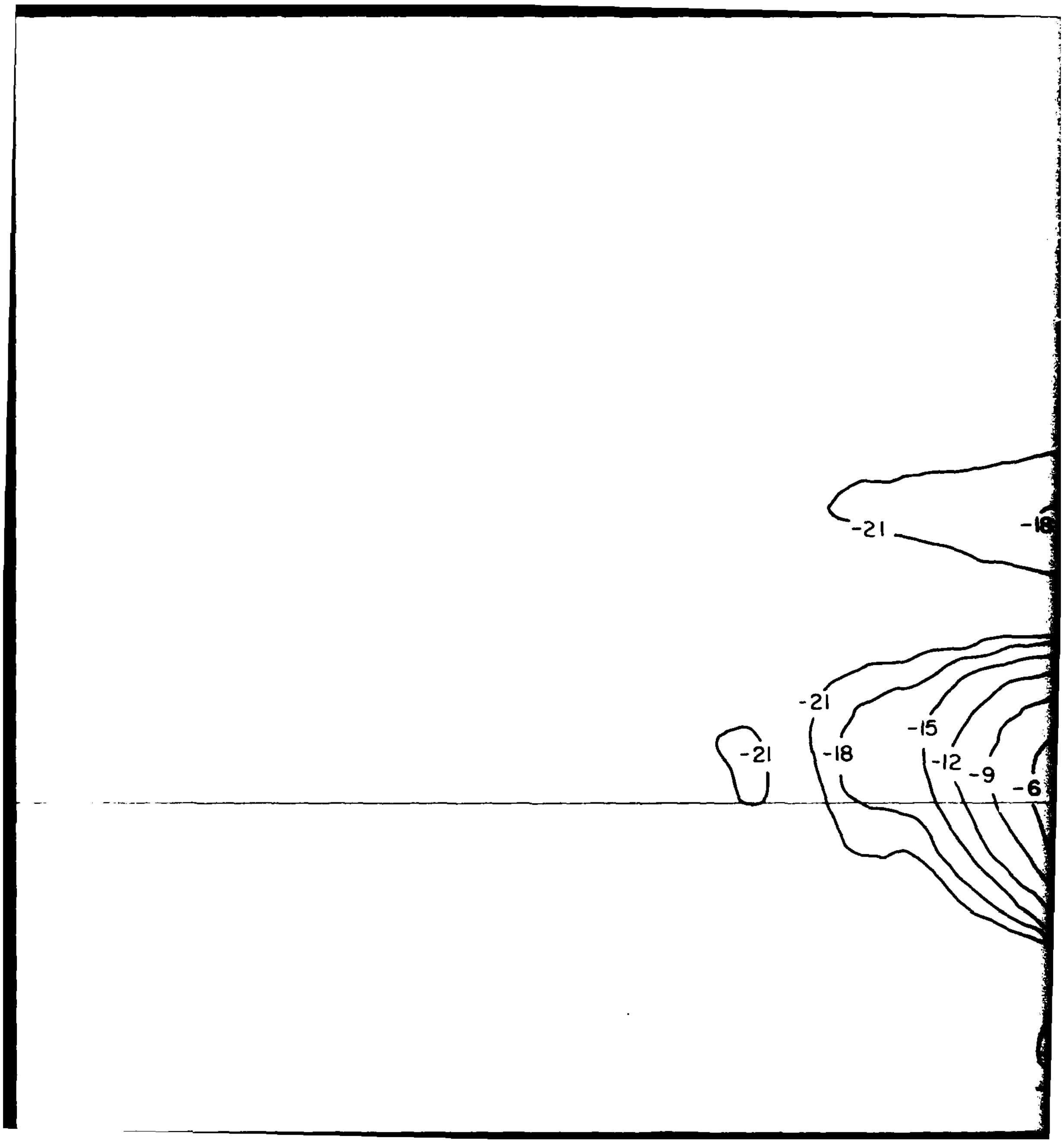

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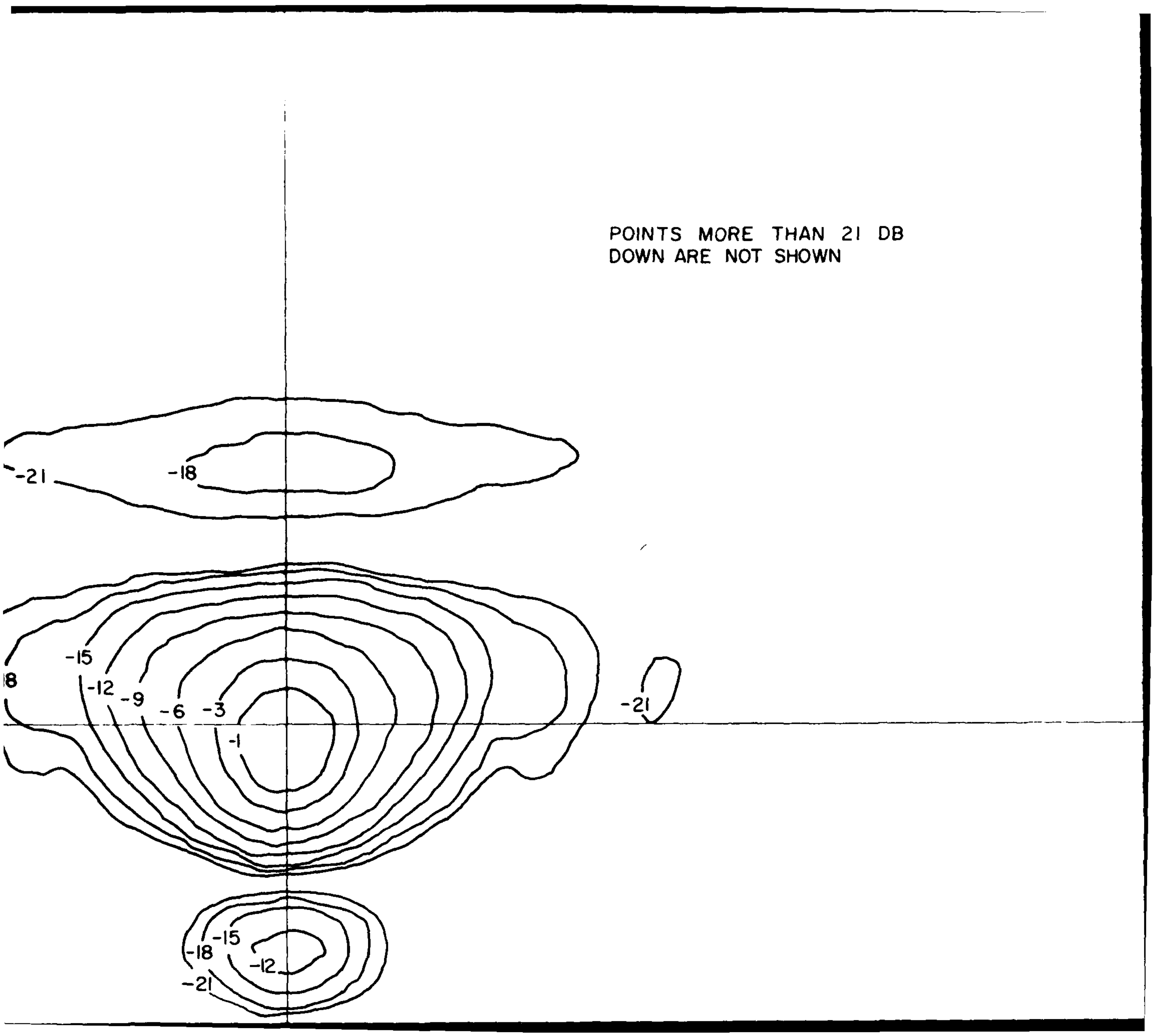
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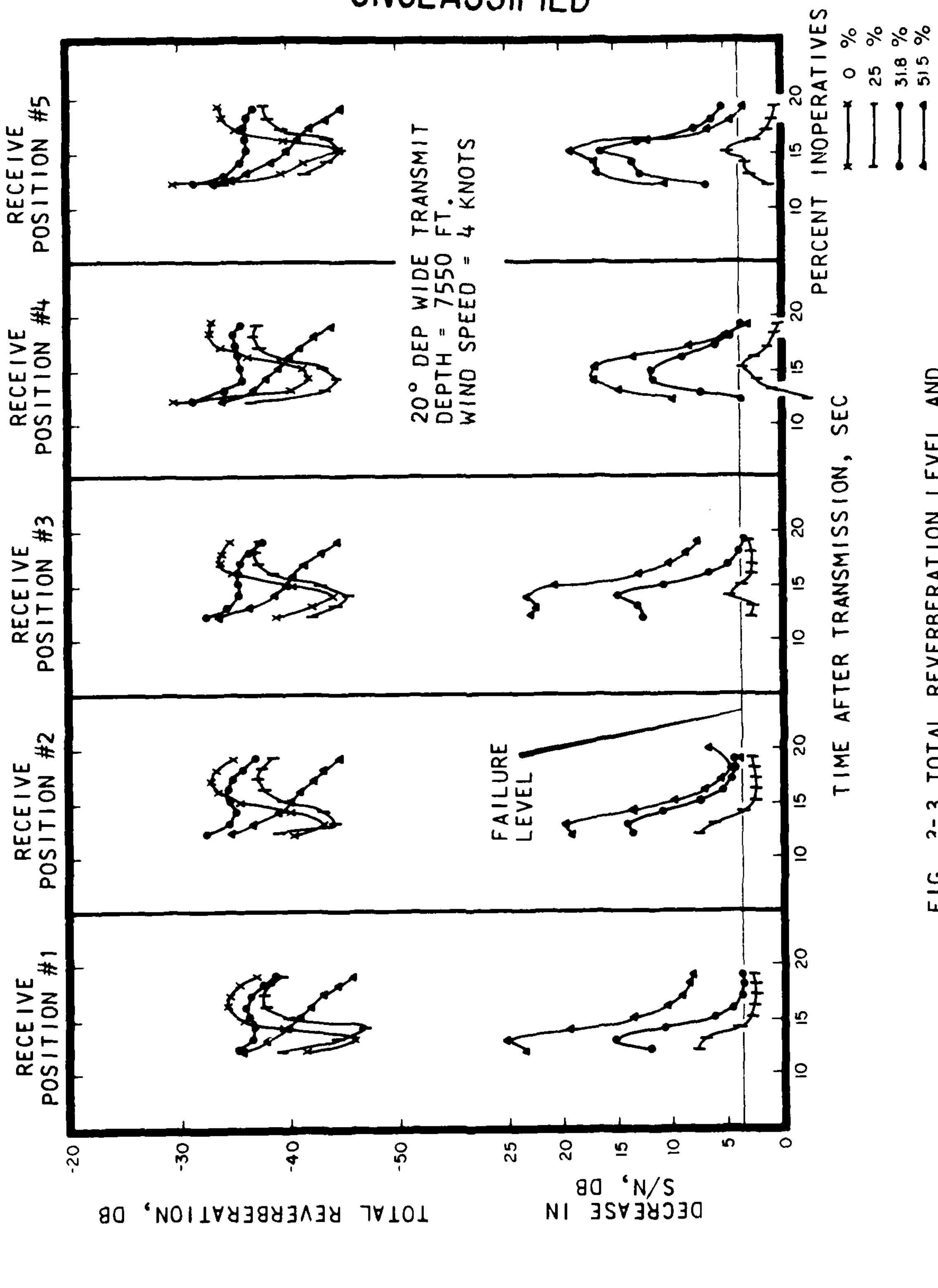

FIG. 2-3 TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

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4. SUMMARY AND CONCLUSIONS

The results presented in this section assume that the sonar is operated with a clutter rate of one mark per second or less, in which case a decrease in signal-to-noise ratio of 3.7 dB will cause a decrease in signal detection probability from 0.75 to 0.25, and a system failure will be declared. The results are presented for wide transmit patterns with depression angles of 20° and 30°. The reverberation model simulates a triple ping transmission and any number of receive positions, of which five were chosen. The decrease in signal-to-noise ratio is averaged over the five positions. It should be noted that the results of the multiple positions when elements are inoperative is not an exact representation, since at each position a different array would be encountered in practice, and the model assumes the same element failures for each position. However, the average across the five positions is considered representative of what would be obtained if the element loss configuration were changed for each position. Three wind speeds and four depths are considered.

Figures 4-1 and 4-2 show the decrease in the signal-to-noise ratio averaged over five receive positions for depression angles of 20° and 30°, respectively. The dependence of the decrease in S/N on depth, wind speed, and the percentage of inoperative elements is shown.

Operating with 25% random inoperatives for a 20° depression angle, it is concluded that the system operates within the specified limits (i.e., the decrease in S/N is less than 3.7 dB). However, with 20° depression and 31.8% inoperatives a definite system failure occurs for depths less than or equal to 13,300 ft and wind speeds less than or equal to 12 knots. Operation in the remaining cases is questionable except for a depth of 16,400 ft and wind speed of 20 knots where the decrease is within tolerable limits.

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For 30° depression and 31.8% inoperatives, a system failure generally occurs for a wind speed of 4 knots. Operation is questionable (i.e., the decrease is close to 3.7 dB) for a wind speed of 12 knots. The system operates properly for a wind speed of 20 knots.

In the event of 51.5% random element failures, the performance of the system at either depression angle is totally unacceptable with respect to bottom bounce operation.

Therefore, it is concluded that operating under the assumed conditions, the system operates satisfactorily with 25% inoperatives, but a system failure occurs with 51.5% inoperatives. A cross-over point (i.e. from acceptable operation to failure state) is near 31.8% inoperatives but depends on the different parameters such as depression angle and wind speed.

The decrease in the signal-to-noise ratio generally increases with decreasing wind speeds. The reason is that the total reverberation level includes an increasing amount of surface reverberation as the wind speed increases, and the surface reverberation, in the time window considered[6], is almost entirely dependent upon the main lobe of the beam pattern. The effect is that as the main lobe decreases due to element failures, the reverberation level likewise decreases, and the signal-to-noise ratio is not affected as much as in the cases where the reverberation level is affected by the side lobes.

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6 Bell, Thaddeus, "Operating the AN/SQS-26 Sonar in the Ocean Environment (U)", U. S. Navy Underwater Sound Laboratory, Report 726, Fort Trumbull, New London, Connecticut, 14 April 1966 (Confidential).

Failures of entire layers or staves were not considered since, in an earlier report[7], it was shown that such failures increase the side lobe level substantially, and it was concluded that failures of that type will cause a system failure.

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[7] Tucker, et. al., op. cit.

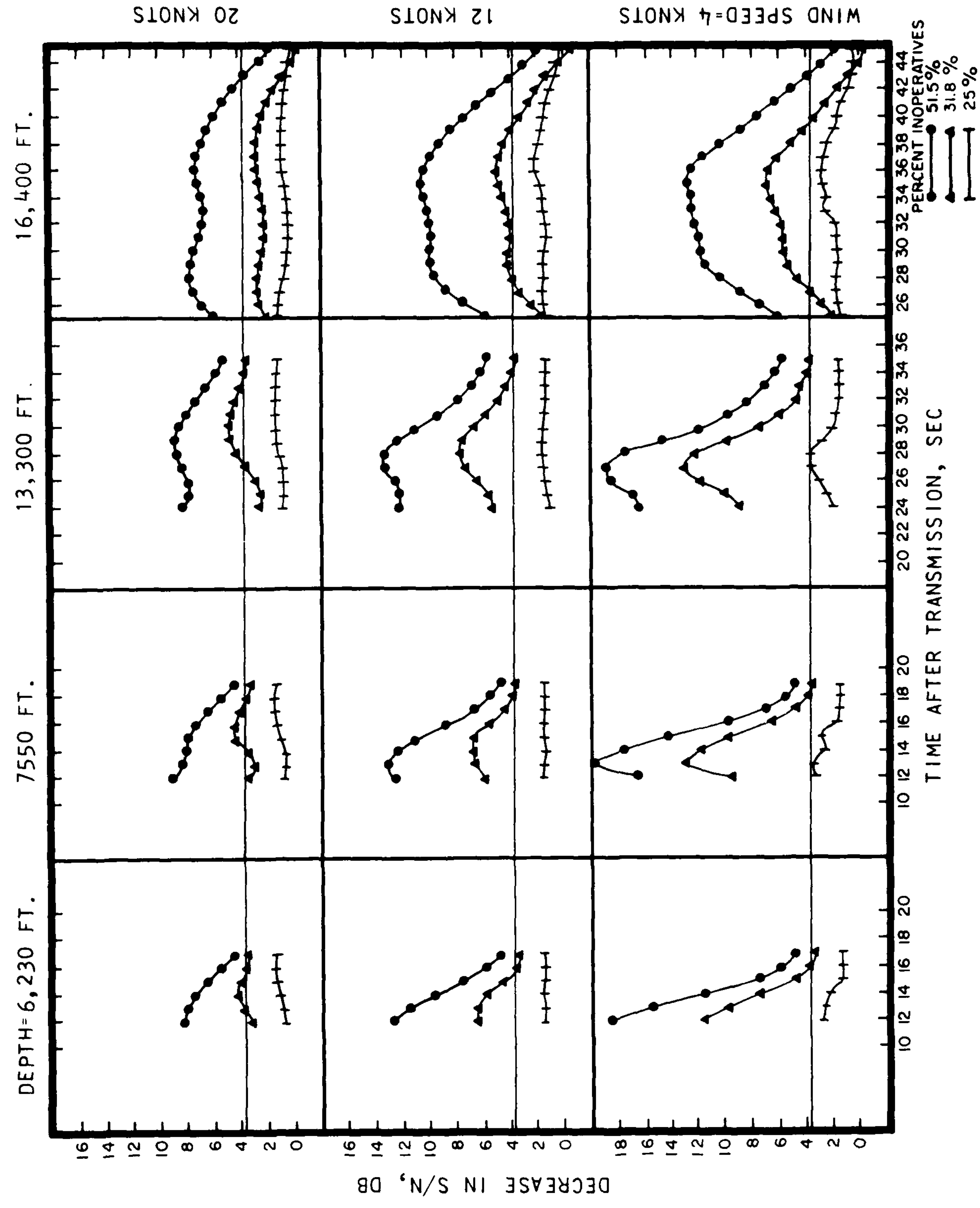

FIG. 4-1 - AVERAGE SIGNAL-TO-NOISE RATIO DECREASE FOR 20° DEPRESSION WIDE TRANSMIT

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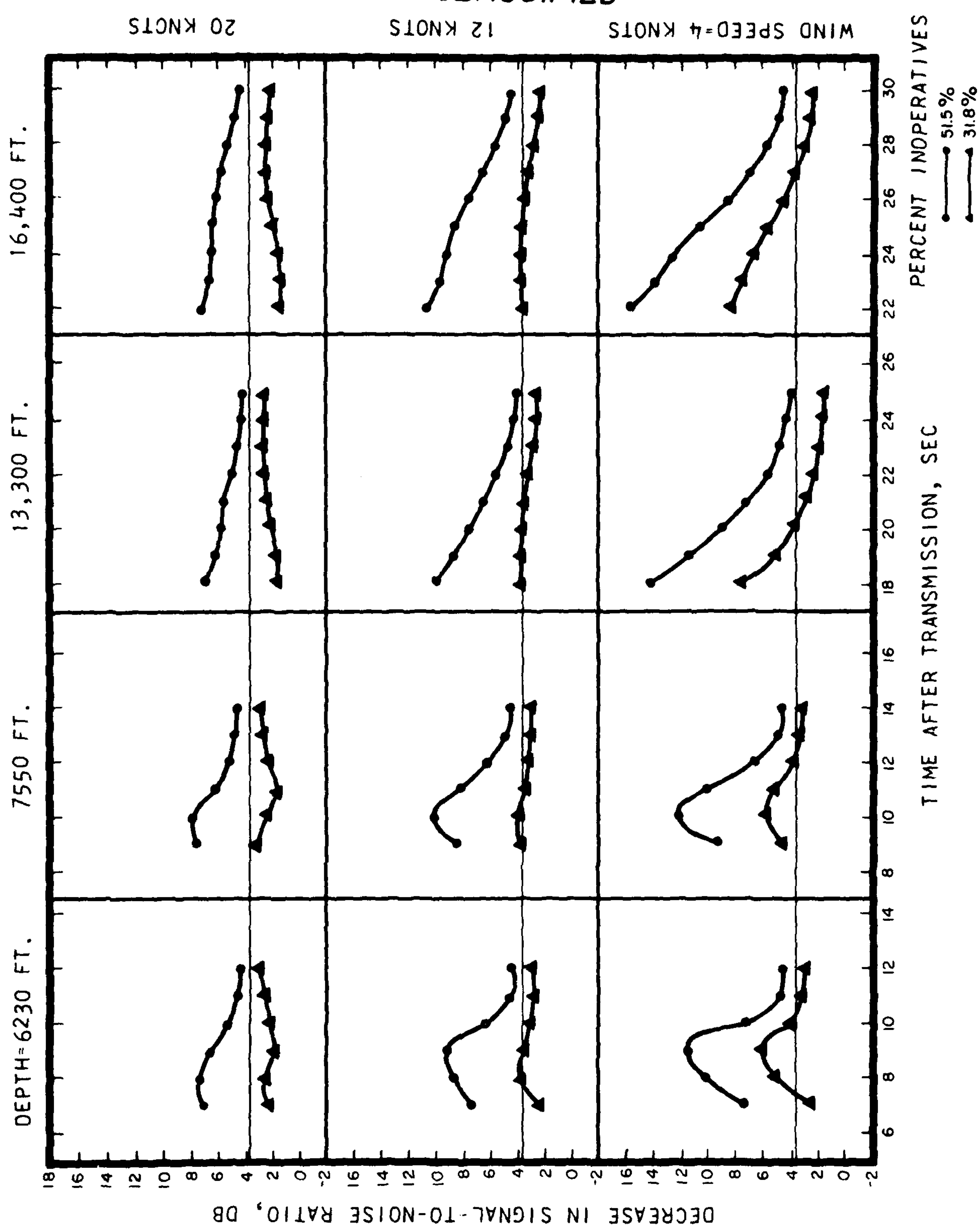

FIG. 4-2 - AVERAGE SIGNAL-TO-NOISE RATIO DECREASE FOR 30° DEPRESSION WIDE TRANSMIT

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APPENDIX A

THREE-DIMENSIONAL BEAM PATTERNS

INTRODUCTION

The technique for computing three-dimensional beam patterns is essentially the same as that used in earlier investigations at TRACOR[1]. Although the basic equations are the same, several modifications have been made for faster computing times. The modifications, however, are peculiar to a cylindrical transducer such as the AN/SQS-26 CX.

Computation of the beam patterns is accomplished in the following manner: (1) Project all elements onto a line defined by the azimuthal angle α and the depression angle θ; (2) perform a Fourier transform on the equivalent line array where each element is weighted by an appropriate complex weight corresponding to the shading and phasing factors(shown in Table A-I) and the individual element response. The improved computation time is realized by recognizing that the equivalent line array repeats itself (except for the end elements) at azimuthal angle increments of five degrees, and also by noting that the individual phone response is zero at angles, $(\varphi_j - \alpha)$, greater than 90° where $(\varphi_j - \alpha)$ is defined in Fig. A-1.

DERIVATIONS AND GEOMETRY

The general form of the Fourier transform is

$$W(u) = \sum_x \omega(x)\, e^{j2\pi ux}.$$

1 Fowler, Steve, "Bottom Bounce Reverberation Model and Bottom Loss Analysis (U)", TRACOR, Inc., Tech. Memo. 66-355-C, Contract NObsr-93140, 16 November 1966, (Confidential).

TABLE A-I

HORIZONTAL AND VERTICAL PHASINGS AND SHADING FOR AN/SQS-26CX FOR 20° & 30° DEPRESSION AT MID-FREQUENCY FOR WIDE TRANSMIT

STAVE	HST(20°)	HST(30° DEPRESSION)	BEAM HSR (20°&30°)	HPT(20°)	HPT(30°)	HPR (20°&30°)
1,24	0.0	0.0	0.315	0.0	0.0	1000.0
2,23	1.0	0.0	0.265	51.0	0.0	845.0
3,22	1.0	1.0	0.315	341.0	296.0	699.0
4,31	1.0	1.0	0.390	272.0	236.0	567.0
5,20	1.0	1.0	0.475	211.0	185.0	440.0
6,19	1.0	1.0	0.570	164.0	142.0	338.0
7,18	1.0	1.0	0.665	116.0	103.0	245.0
8,17	1.0	1.0	0.760	72.0	61.0	162.0
9,16	1.0	1.0	0.850	51.0	39.0	96.0
10,15	1.0	1.0	0.925	19.0	19.0	49.7
11,14	1.0	1.0	0.980	8.0	8.0	17.8
12,13	1.0	1.0	1.000	0.0	0.0	0.0

LAYER	VSR = VST(20° & 30°)	VPT = VPR(20°)	VPT = VPR(30°)
1	1.0	0.0	0.0
2	1.0	59.0	87.0
3	1.0	119.0	174.0
4	1.0	179.0	261.0
5	1.0	238.0	348.0
6	1.0	297.0	435.0
7	1.0	357.0	522.0
8	1.0	416.0	609.0

The Fourier transform can also be written as

$$W(u) = \sum_{x} [\omega(x)] [\cos(2\pi ux) + j \sin(2\pi ux)] .$$

Figure A-1 shows the geometry assumed throughout the beam pattern computations. First, the element staves are projected onto a plane defined by the azimuthal angle, α. The projections, A_k, measured from the center of the transducer are given by

$$A_k = R \cos(\varphi_k - \alpha) \quad k = 1, . . ., 24 \quad ,$$

where φ_k is in increments of 5° from 32.5° to 147.5° and R is the radius of the transducer.

Now each element in the plane is projected onto a line in the plane that passes through the center of the transducer and makes an angle, θ, with the horizontal. The angles, α and θ, provide the "look" direction. The projections are given by

$$E_{ik} = D_{ik} \cos (\zeta_{ik} - \theta) = A_{ik}\left(\frac{\cos(\zeta_{ik} - \theta)}{\cos(\zeta_{ik})}\right),$$

where

$$\zeta_{ik} = \mathrm{Tan}^{-1}\left(\frac{i \cdot s}{A_k}\right) .$$

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Now consider,

$$B_{ik} = \cos(\frac{2\pi}{\lambda} E_{ik}),$$

$$P_{ik} = \sin(\frac{2\pi}{\lambda} E_{ik}),$$

$$C_{ik} = HST_k \cdot VST_i \{\cos[HPT_k - VPT_i]\} W[(\varphi_k - \alpha), \theta],$$

$$D_{ik} = HST_k \cdot VST_i \{\sin[HPT_k - VPT_i]\} W[(\varphi_k - \alpha), \theta],$$

where

$HST_k(HSR_k)$ = horizontal shading for transmit (receive) for k^{th} stave,

$VST_i(VSR_i)$ = vertical shading for transmit (receive) for i^{th} row,

$HPT_k(HPR_k)$ = horizontal phasing for transmit (receive) for k^{th} stave,

$VPT_i(VPR_i)$ = vertical phasing for transmit (receive) for i^{th} row.

$$W[(\varphi_k - \alpha), \theta] = \left\{\frac{\sin[qa \cos\theta \sin(\varphi_k - \alpha)]}{qa \cos\theta \sin(\varphi_k - \alpha)}\right\}\frac{\sin(qa \sin\theta)}{qa \sin\theta}$$

= phone response,

where

$$q = \frac{2\pi}{\lambda}, \quad a = \text{element half-width.}$$

Let

$$R(\alpha,\theta) = \sum_{i,k} (C_{ik} + j\,D_{ik})\,(B_{ik} + j\,P_{ik})$$

$$= \sum_{i,k} \left\{ (C_{ik} + j\,D_{ik})\,[\cos(\tfrac{2\pi}{\lambda}\,E_{ik}) + j\,\sin(\tfrac{2\pi}{\lambda}\,E_{ik})] \right\}$$

$$= \sum_{i,k} \left\{ HST_k \cdot VST_i \cdot W[(\varphi_k-\alpha),\theta]\,\{\cos[HPT_k-VPT_i] \right.$$

$$\left. + j\,\sin[HPT_k-VPT_i]\}\,[\cos(\tfrac{2\pi}{\lambda}\,E_{ik}) + j\,\sin(\tfrac{2\pi}{\lambda}\,E_{ik})] \right\}$$

$$R(\alpha,\theta) = \sum_{i,k} HST_i \cdot VST_i \cdot W[\varphi_k-\alpha),\theta]\,e^{j[\frac{2\pi}{\lambda}E_{ik} + (HPT_k-VPT_i)]},$$

which is the form of the Fourier transform. To find an expression for the intensity we multiply $R(\alpha,\theta)$ by its complex conjugate, i.e.

$$I = [R(\alpha,\theta)] \cdot [R(\alpha,\theta)]^*$$

The number of sine and cosine functions that must be computed is decreased considerably by considering $R(\alpha,\theta)$ in the following form:

$$R(\alpha,\theta) = \sum_{i,k} \left\{ (C_{ik} + j\,D_{ik})\,[\cos(\tfrac{2\pi}{\lambda}\,E_{ik}) + j\,\sin(\tfrac{2\pi}{\lambda}\,E_{ik})] \right\}.$$

The argument E_{ik} is repeated (except for the end elements) at regular alpha increments, and therefore for a given value of depression angle a table of sine and cosine values is tabulated and referenced as required and not computed for each azimuthal angle. The size of the table is reduced by realizing that the phone response is zero for values of $(\varphi_k - \alpha) > 90°$.

It should be noted that repetition of the exponential argument occurs only in the case of cylindrical arrays. Therefore, the time savings realized by tabulating the sine and cosine values would be lost in the case of transducer arrays of different shapes.

Figures A-2 through A-15 show constant depression angle slices through the main lobe of the three-dimensional beam patterns used in this study. The patterns are presented for two depression angles and various numbers of element failures. Three-dimensional printed contour plots of all beam patterns are shown in Figs.A-17 through A-30. Instead of plotting lines of constant power the power associated with each (α,θ) pair is plotted to an accuracy of one dB and presented as a unique symbol. For example, if for $\alpha=118^{\circ}$ and $\theta=33^{\circ}$, the power associated with that point was 17.3 dB, then the letter, H, corresponding to 17 dB would be printed on the line 118 and 33 spaces from the right hand margin. Figure A-16 shows the power associated with each unique symbol. It is noted that the fractional part of the power is ignored in constructing these plots (e.g., all powers between 10 dB and 11 dB are rounded to 10 dB).

Table A-II gives the row number and column (stave) number of the elements that were deleted in cases corresponding to the different percentages of inoperatives.

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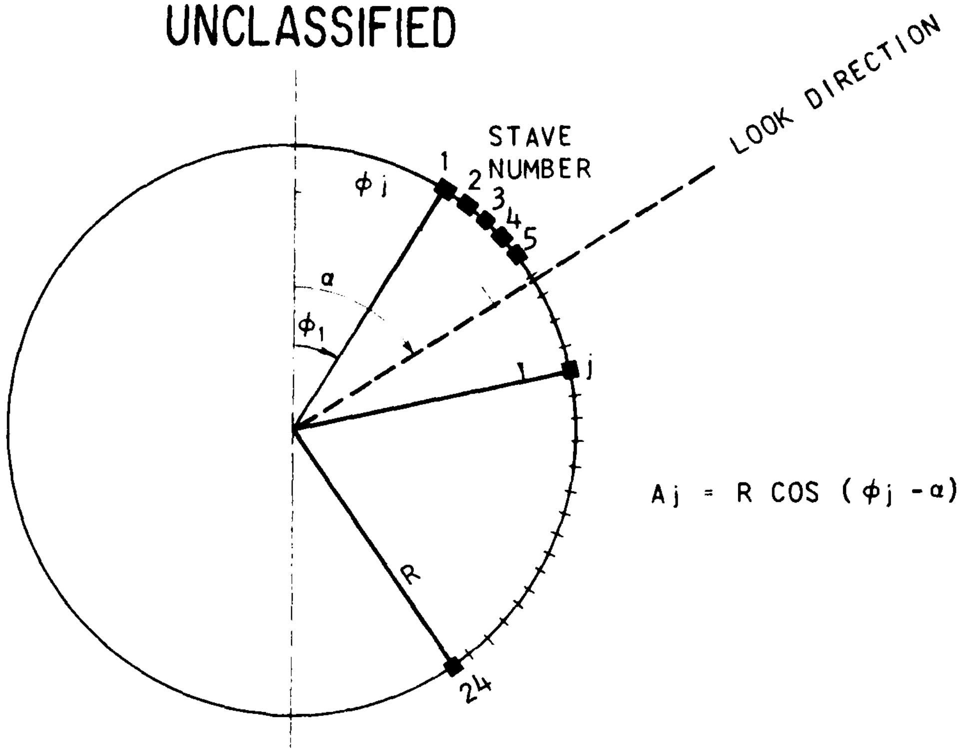
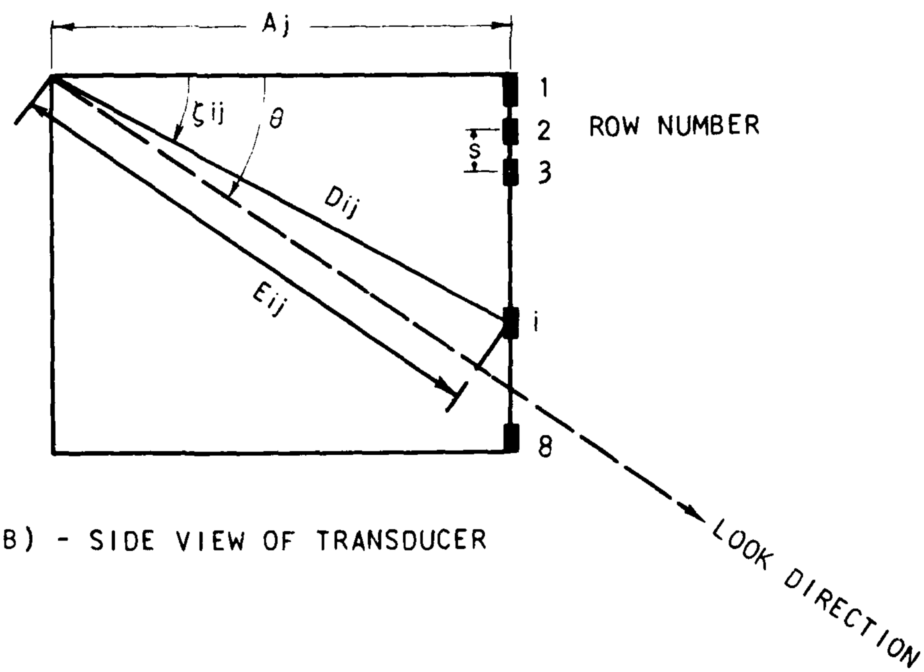
TABLE A-II

LAYER AND STAVE NUMBER OF DIFFERENT NUMBER INOPERATIVES USED IN COMPUTING PERTURBED BEAM PATTERNS

Row	31.8%(61)	25.0%(41)	51.5%(99)
1	2,3,11,13,15,18,20, 21,24	4,8,12,13,17,24	3,4,5,8,9,10,11,14, 15,18,22
2	2,3,10,12,13,18,20, 24	1,8,14,17,21,22	4,5,7,8,9,10,13,14, 15,17,19,21
3	2,5,7,10,14,18,21, 22,23	1,14,21,23	1,3,4,5,7,8,10,11, 12,14,15,16,17,18, 19,21,22,23
4	1,2,6,10,12,14,15 16,18,21,23,24	1,4,13,14,16,20, 22,24	3,6,10,13,14,20,21, 24
5	3,11,19,22,23	8,12,18,21,23	5,7,8,9,12,14,15, 16,17,22,23,24
6	10,11,15,19,20,24	4,11,14,16,20,21, 22	1,2,5,6,10,11,13, 14,15,20,21,22,23,24
7	1,5,7,12	1,2,13,14,21	5,6,8,11,12,13,15,16 17,19,20,22,24
8	6,7,9,12,13,15,18, 20	4,5,7,8,9,18,22	3,6,8,9,10,12,15,18, 20,22,24



(A) - TOP VIEW OF TRANSDUCER



(B) - SIDE VIEW OF TRANSDUCER

FIG. A-1 - TRANSDUCER GEOMETRY

TRACOR, INC DWG A6-13-2101
AUSTIN, TEXAS 5-16-67 McANALLY/S.L.

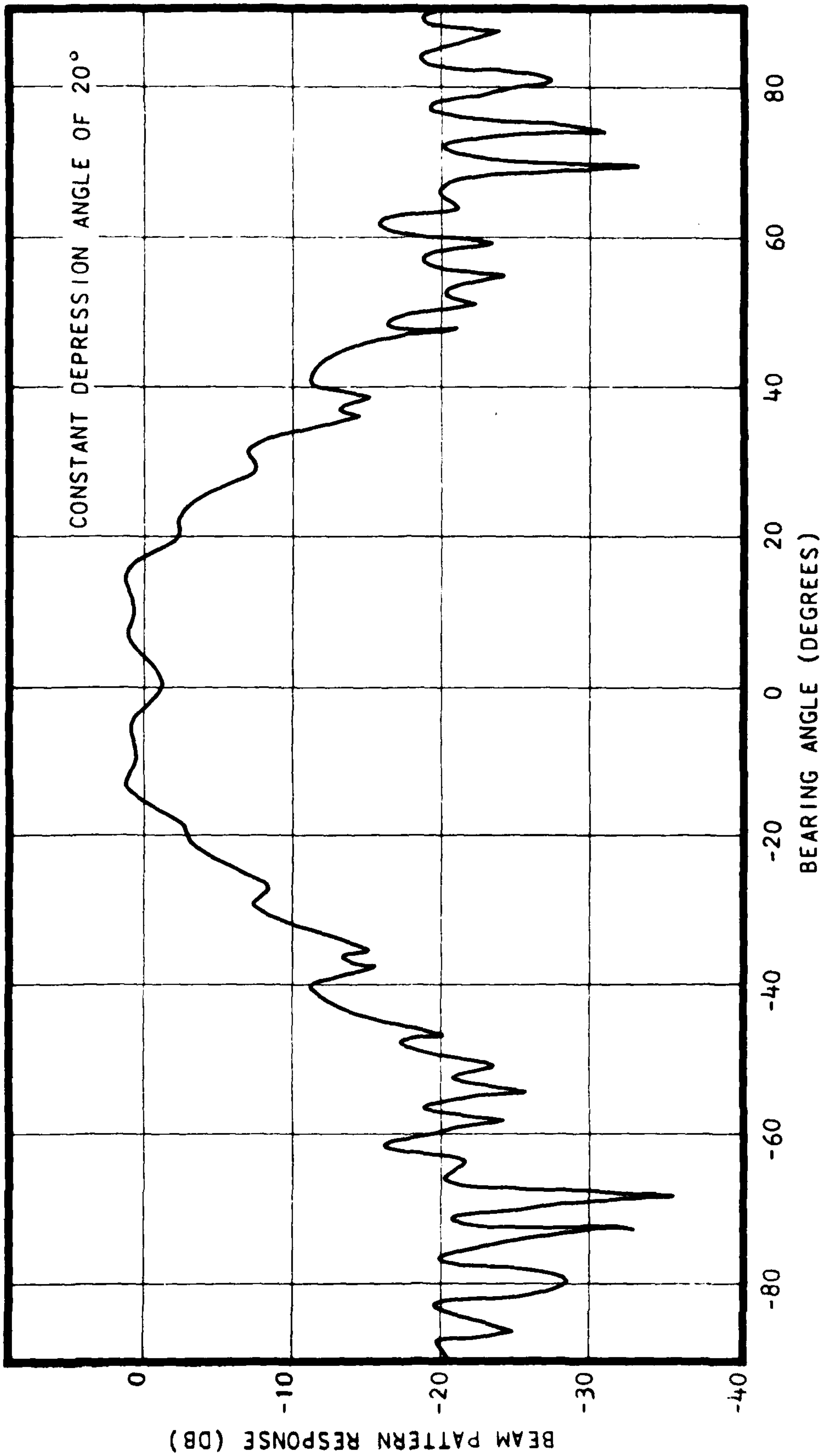


FIG. A-2 - HORIZONTAL SLICE THROUGH 20° DEPRESSED WIDE TRANSMIT BEAM WITH 0% INOPERATIVES

TRACOR, INC | DWG A6-13-2135
AUSTIN, TEXAS 5-16-67 Mc ANALLY/S.D.

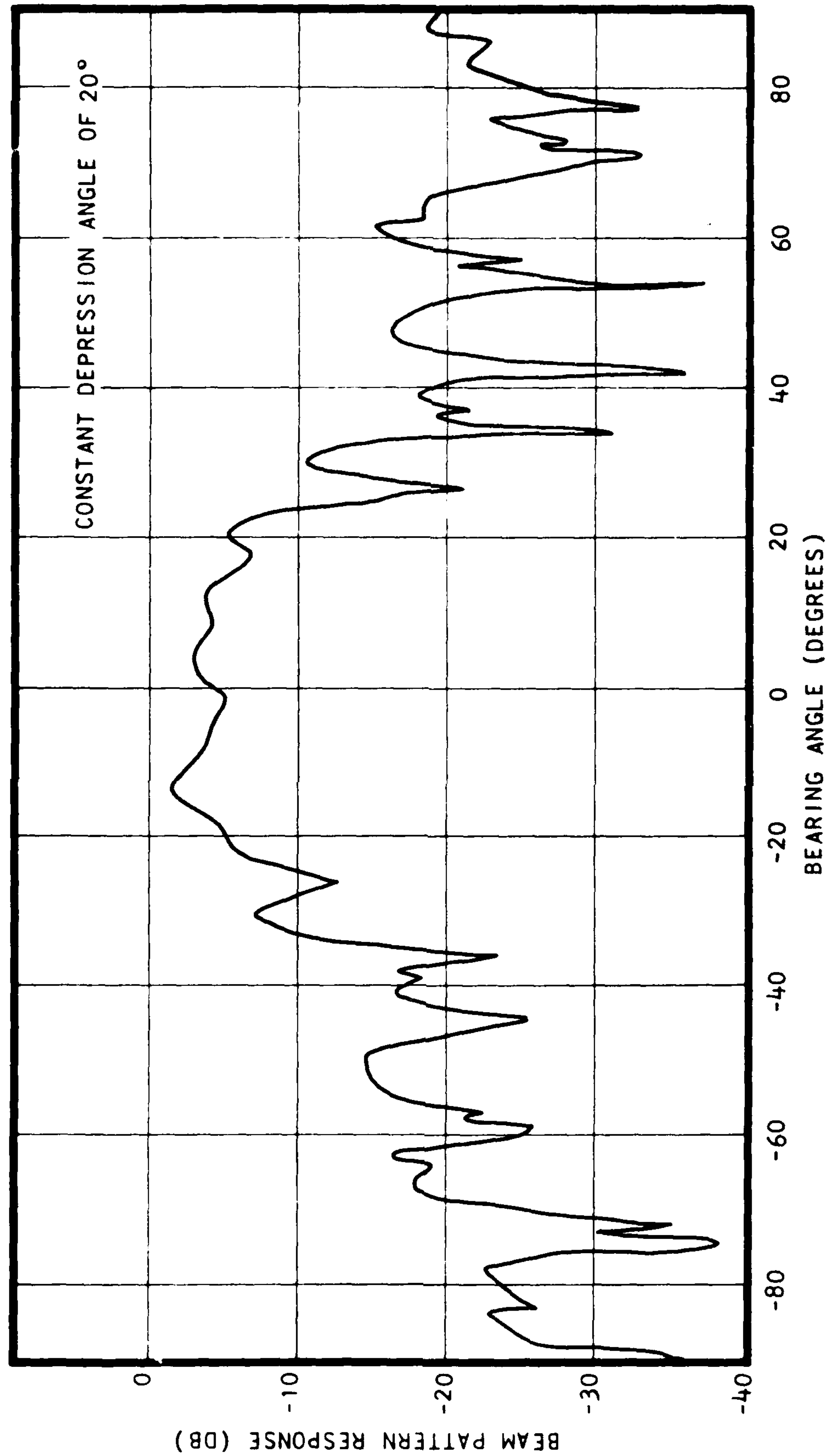


FIG. A-3 - HORIZONTAL SLICE THROUGH 20° DEPRESSED WIDE TRANSMIT BEAM WITH 25% INOPERATIVES

TRACOR, INC | DWG A6-13-2136
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

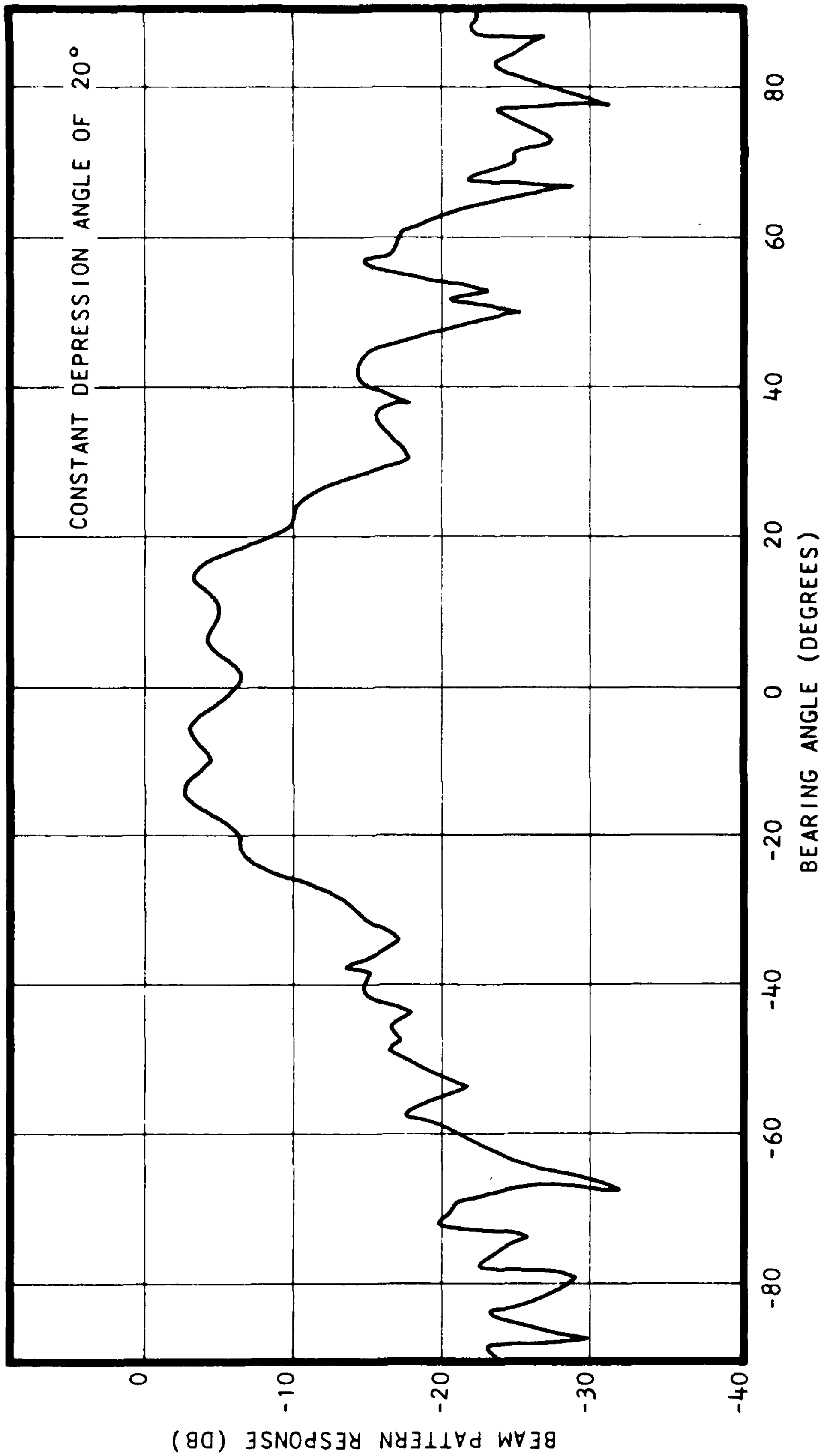


FIG. A-4 - HORIZONTAL SLICE THROUGH 20° DEPRESSED WIDE TRANSMIT BEAM WITH 31.8% INOPERATIVES

TRACOR, INC | DWG A6-13-2131
AUSTIN, TEXAS 5-16-67 McANALLY / S.

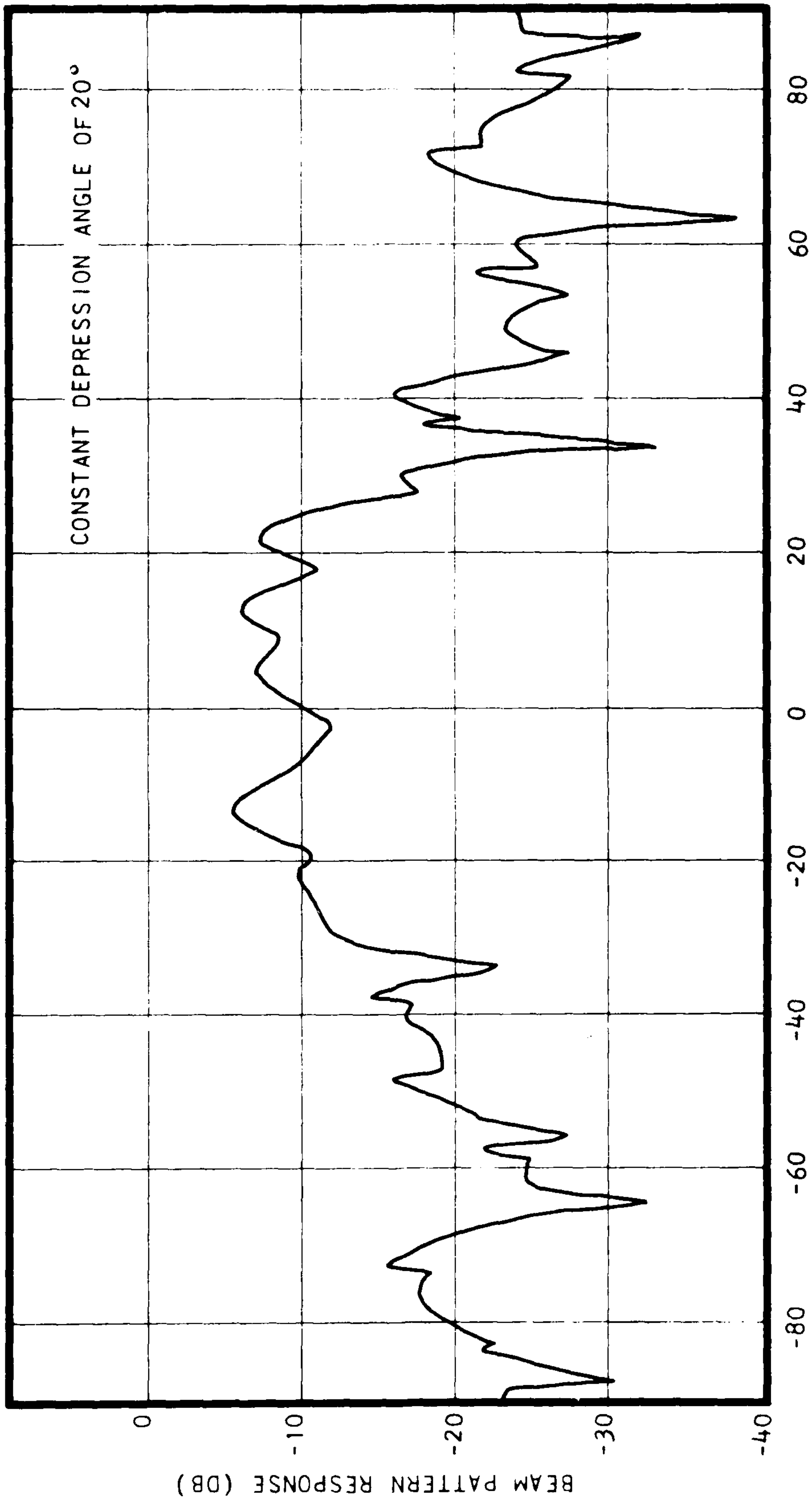


FIG. A-5 - HORIZONTAL SLICE THROUGH 20° DEPRESSED WIDE TRANSMIT BEAM WITH 51.5% INOPERATIVES

TRACOR, INC | DWG A6-13-213
AUSTIN, TEXAS 5-16-67 McANALLY/S.C

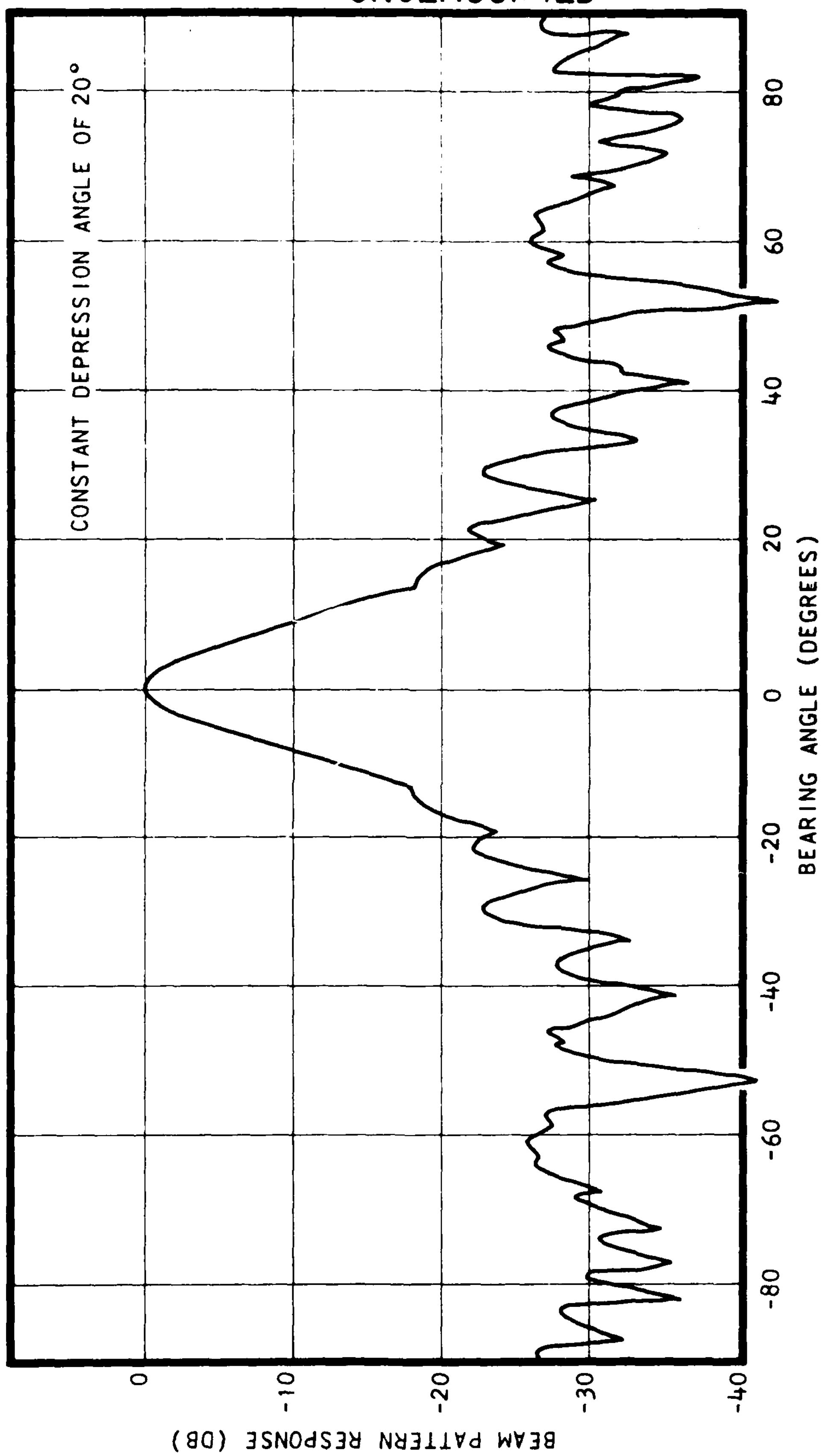


FIG. A-6 - HORIZONTAL SLICE THROUGH 20° DEPRESSED RECEIVE BEAM WITH 0% INOPERATIVES

TRACOR, INC | DWG A6-13-2139
AUSTIN, TEXAS 5-16-67 McANALLY / S.D.

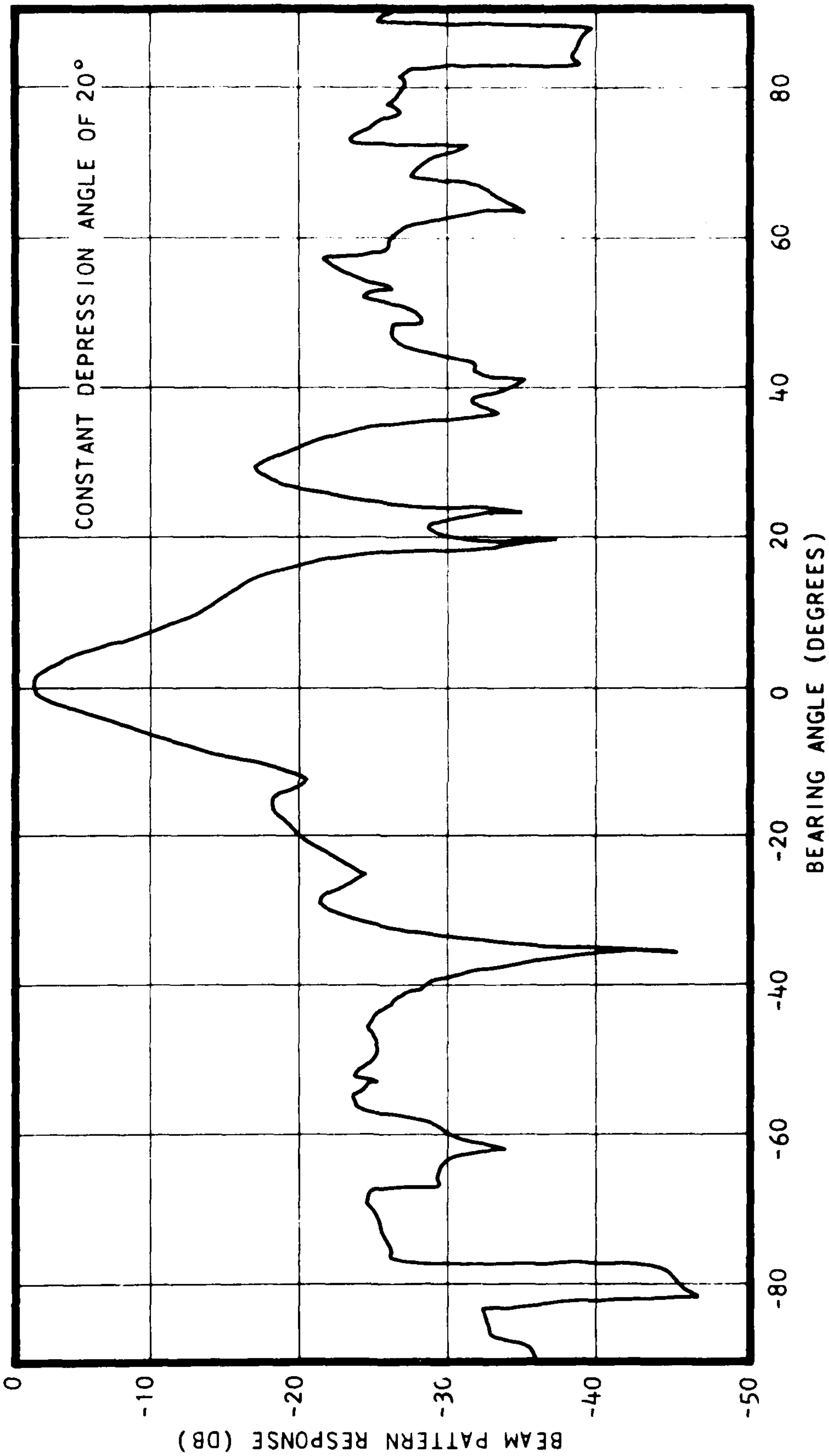


FIG. A-7 - HORIZONTAL SLICE THROUGH 20° DEPRESSED RECEIVE BEAM WITH 25% INOPERATIVES

TRACOR, INC DWG A6-13-2140
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

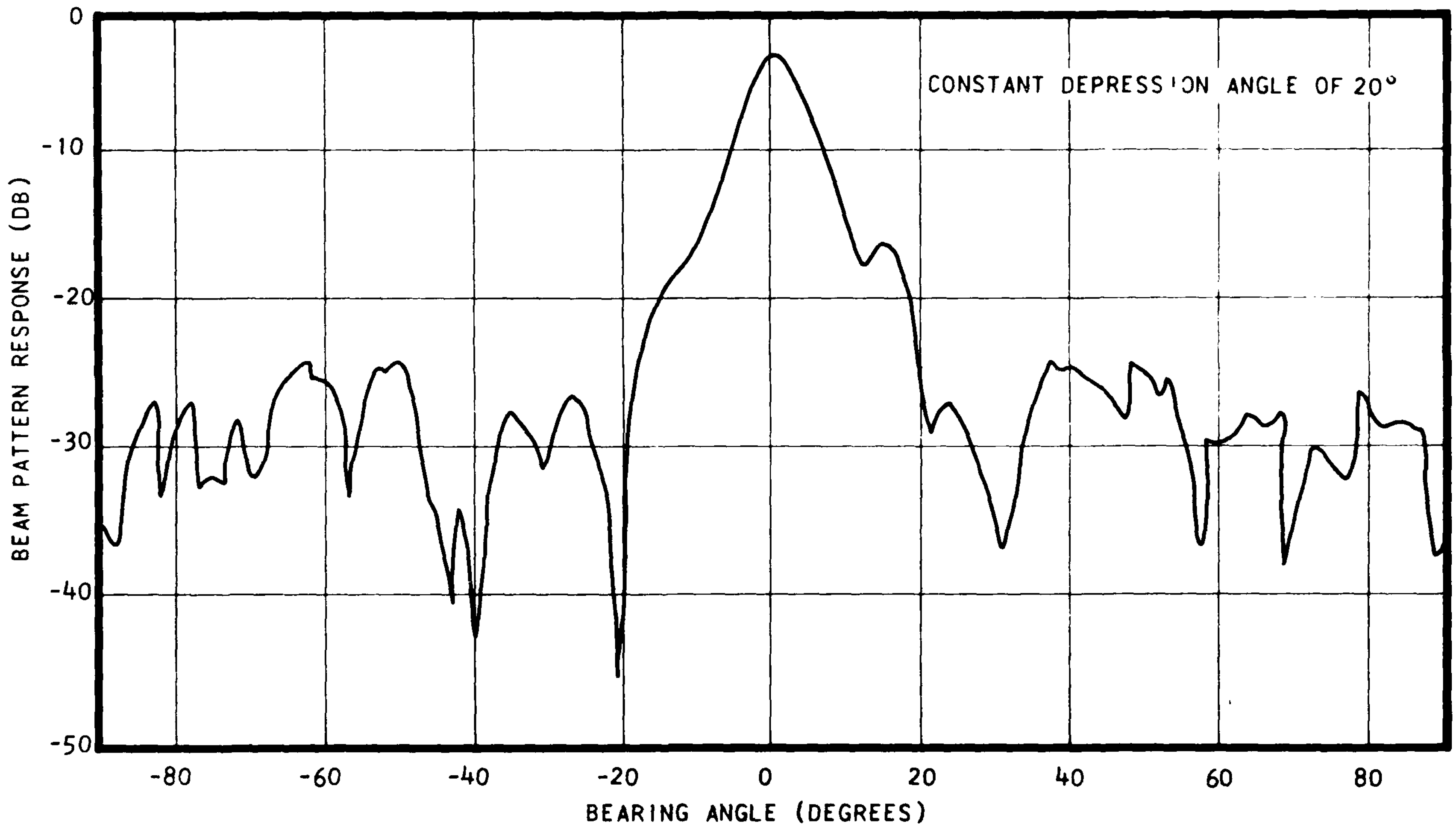


FIG. A-8 - HORIZONTAL SLICE THROUGH 20° DEPRESSED RECEIVE BEAM WITH 31.8% INOPERATIVES

TRACOR, INC. | DWG. A6-13-21
AUSTIN, TEXAS 5-15-67 McANALLY/S.

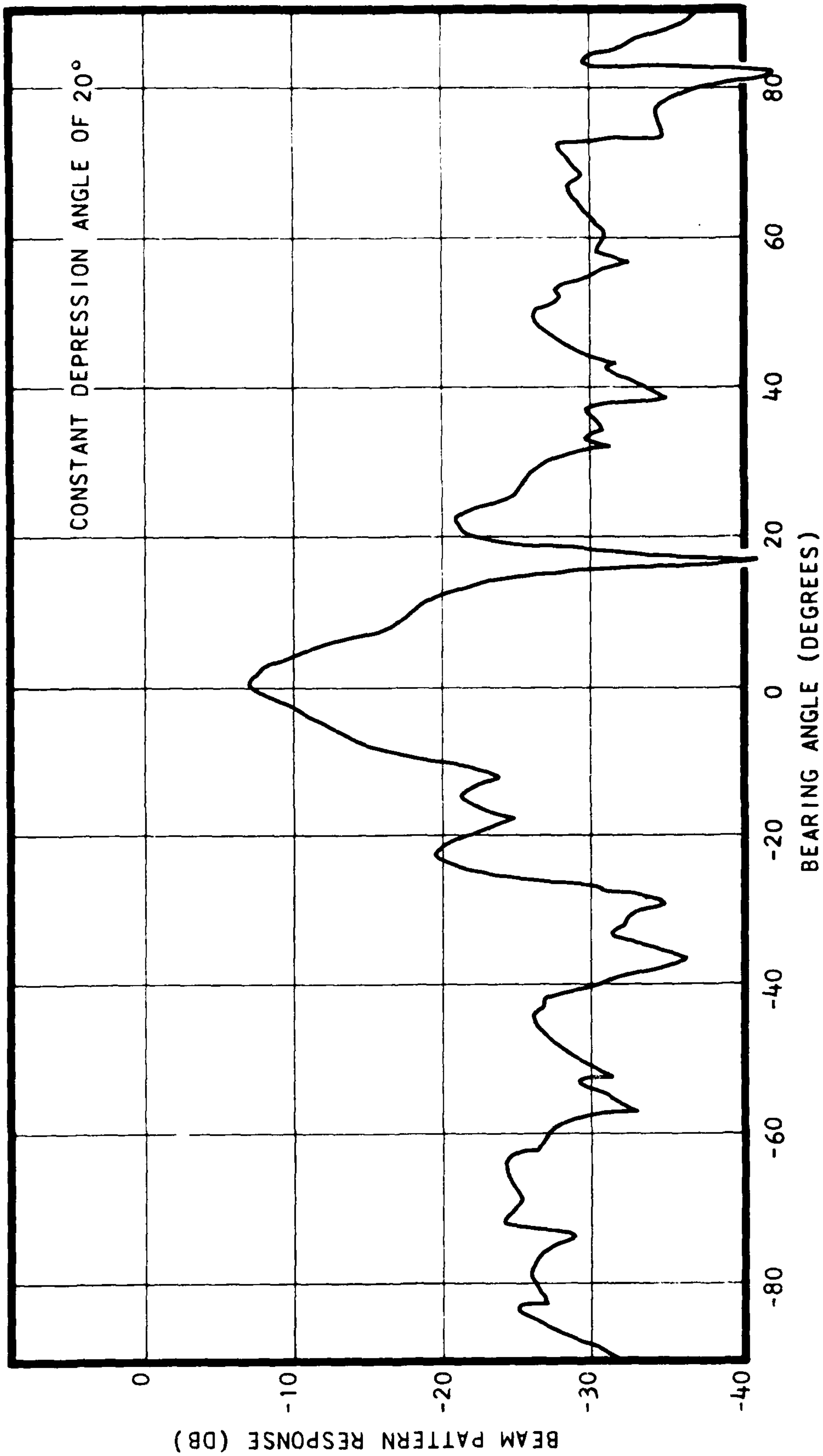


FIG. A-9 - HORIZONTAL SLICE THROUGH 20° DEPRESSED RECEIVE BEAM WITH 51.5% INOPERATIVES

TRACOR, INC. | DWG A6-13-2142
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

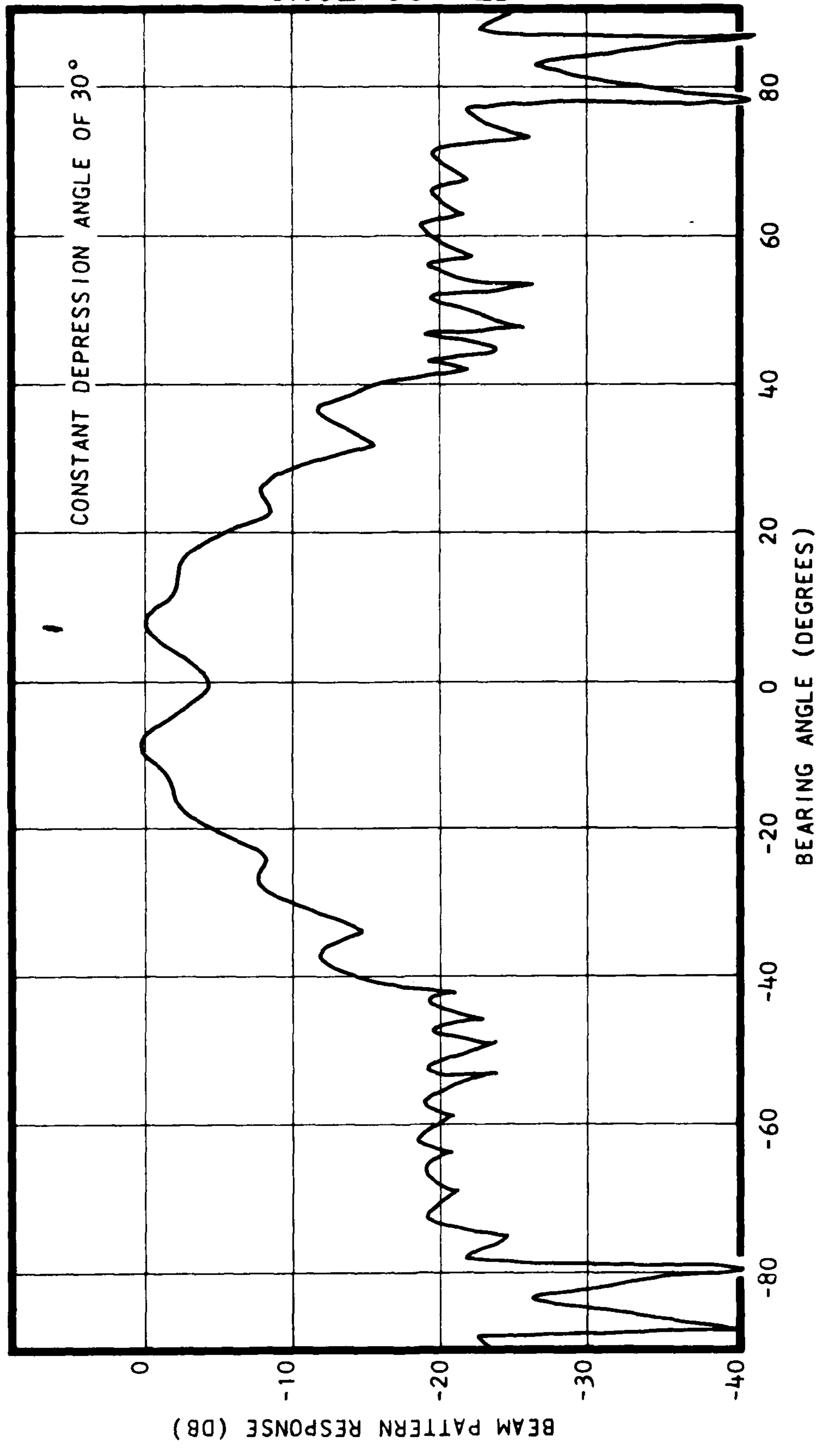


FIG. A-10 - HORIZONTAL SLICE THROUGH 30° DEPRESSED WIDE TRANSMIT BEAM WITH 0% INOPERATIVES

TRACOR, INC | DWG A6-13-2143
AUSTIN, TEXAS 5-16-67 McANALLY / S.D.

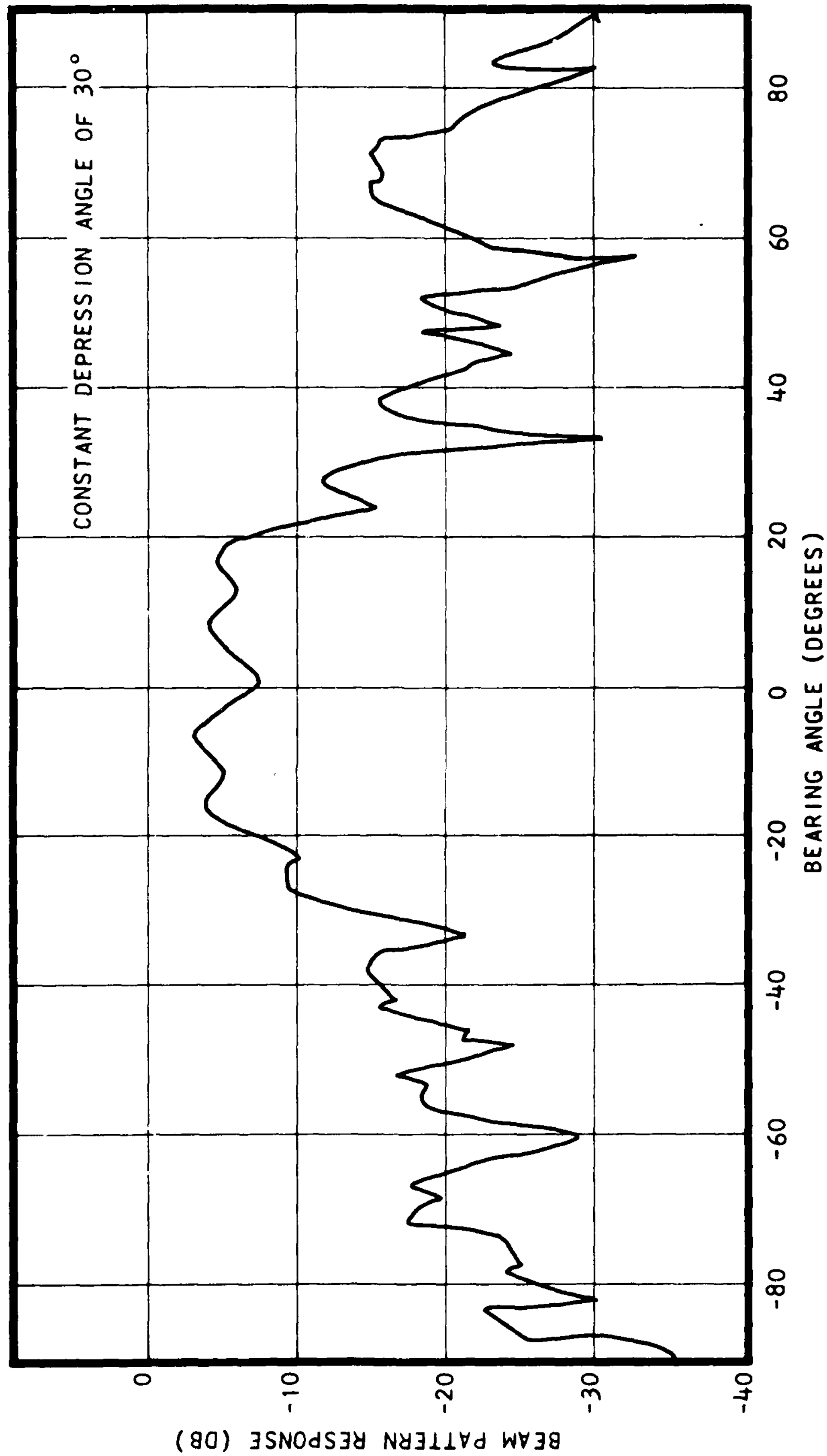


FIG. A-11 - HORIZONTAL SLICE THROUGH 30° DEPRESSED WIDE TRANSMIT BEAM WITH 31.8% INOPERATIVES

TRACOR, INC | DWG A6-13-2144
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

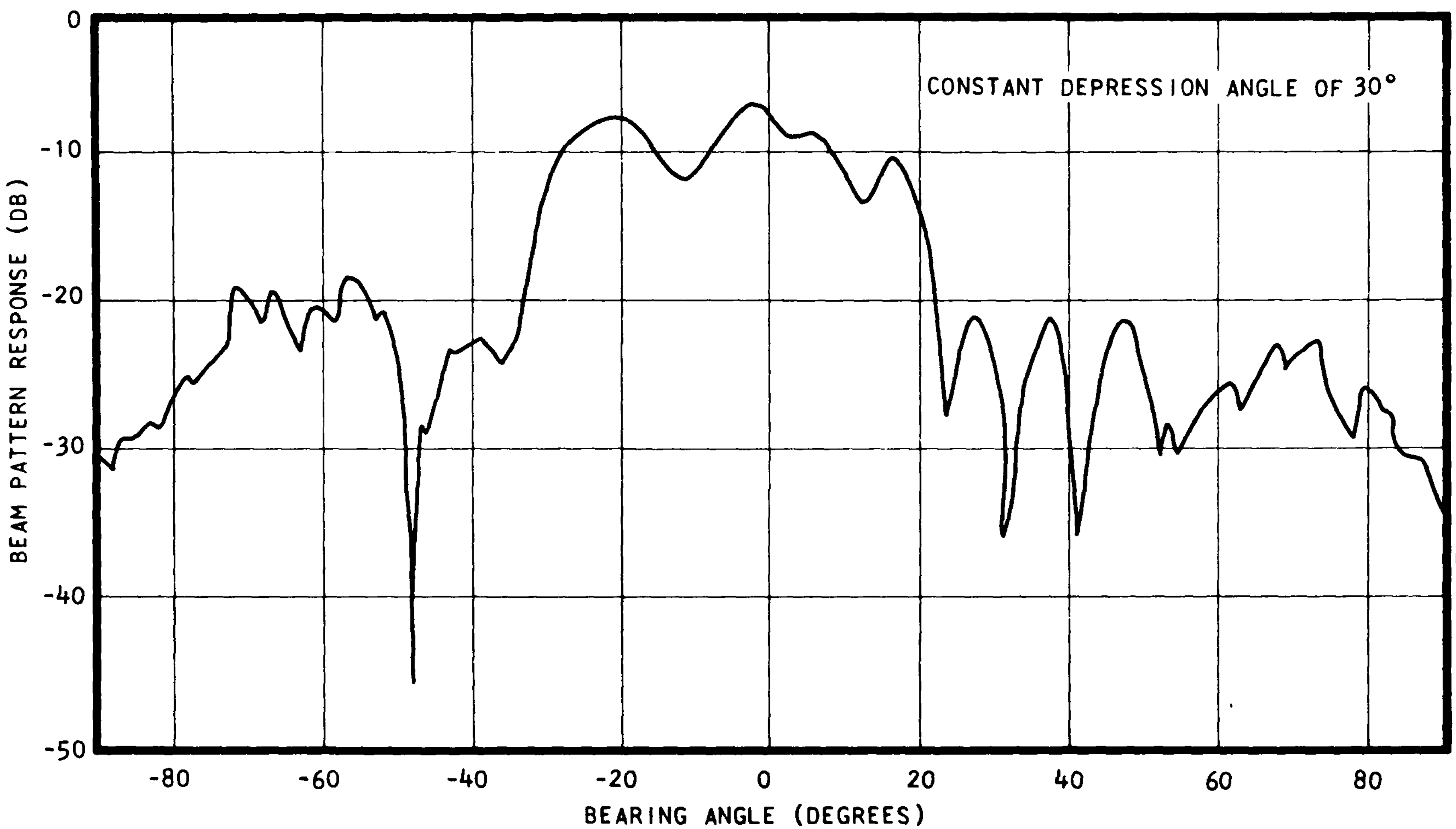


FIG. A-12 - HORIZONTAL SLICE THROUGH 30° DEPRESSED WIDE TRANSMIT BEAM WITH 51.5% INOPERATIVES

TRACOR, INC | DWG A6-13-2145
AUSTIN, TEXAS 5-16-67 McANALLY / S.D.

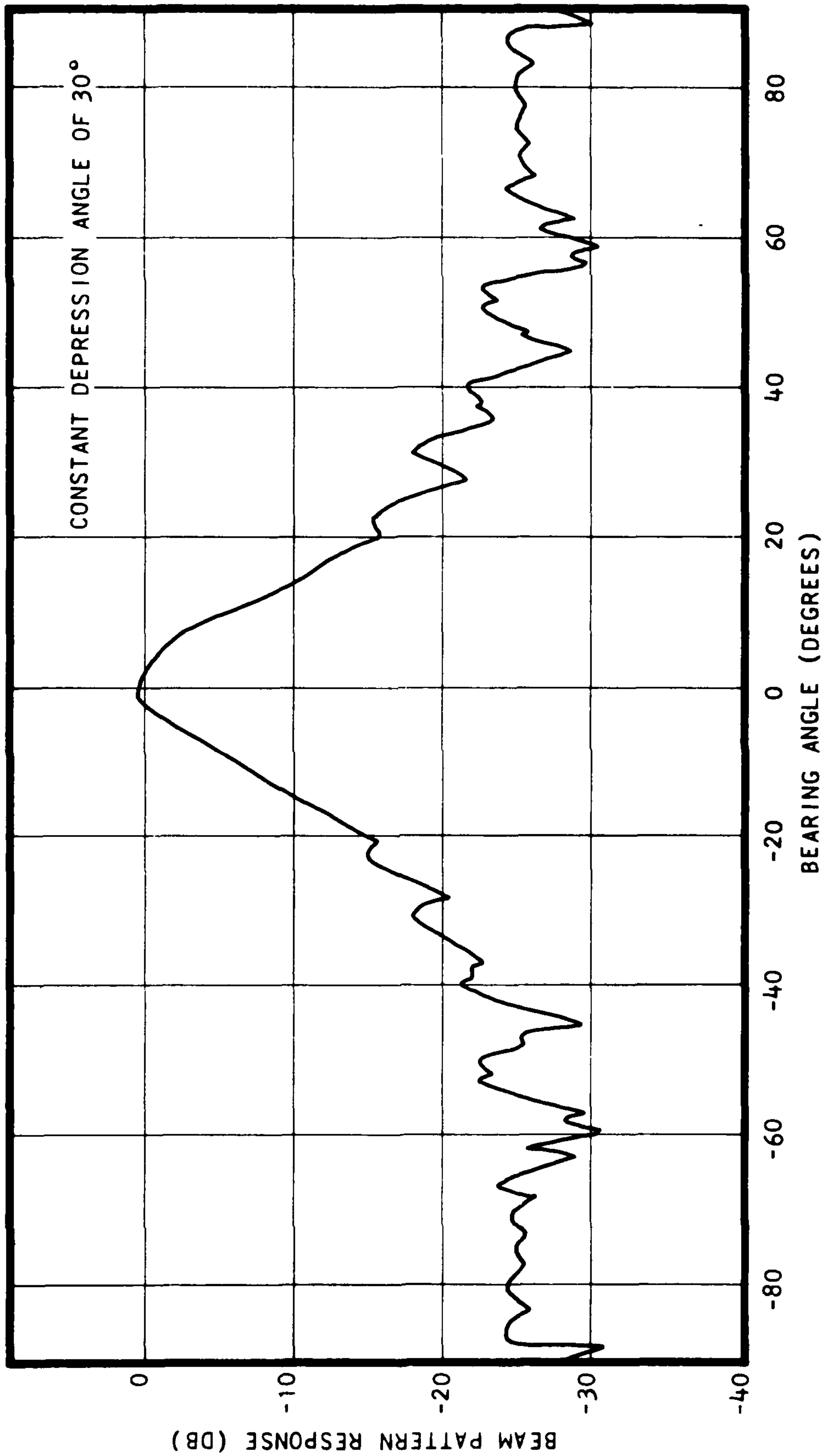


FIG. A-13 - HORIZONTAL SLICE THROUGH 30° DEPRESSED RECEIVE BEAM WITH 0% INOPERATIVES

TRACOR, INC | DWG A6-13-2146
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

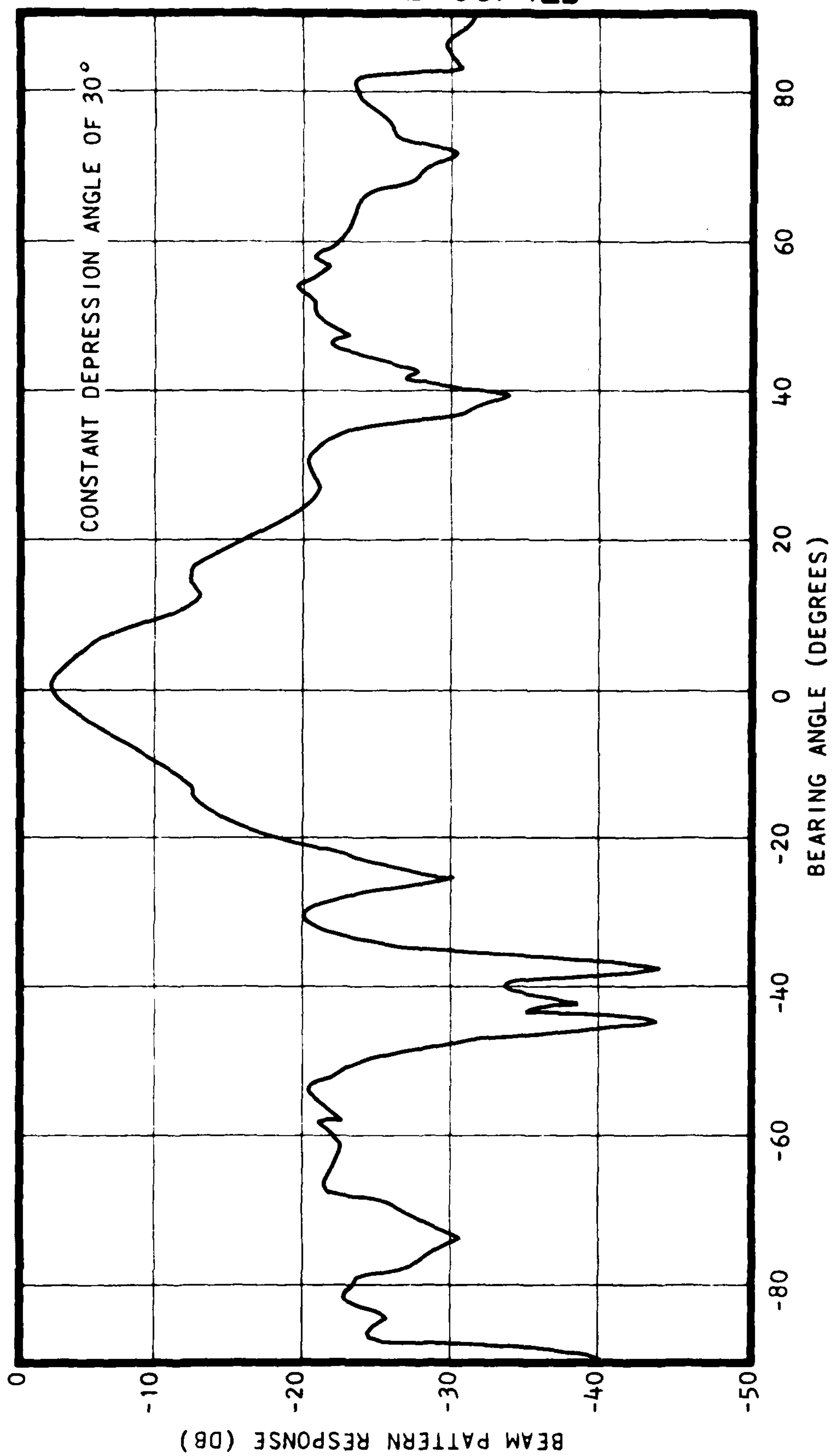


FIG. A-14 - HORIZONTAL SLICE THROUGH 30° DEPRESSED RECEIVE BEAM WITH 31.8% INOPERATIVES

TRACOR, INC | DWG A6-13-2147
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

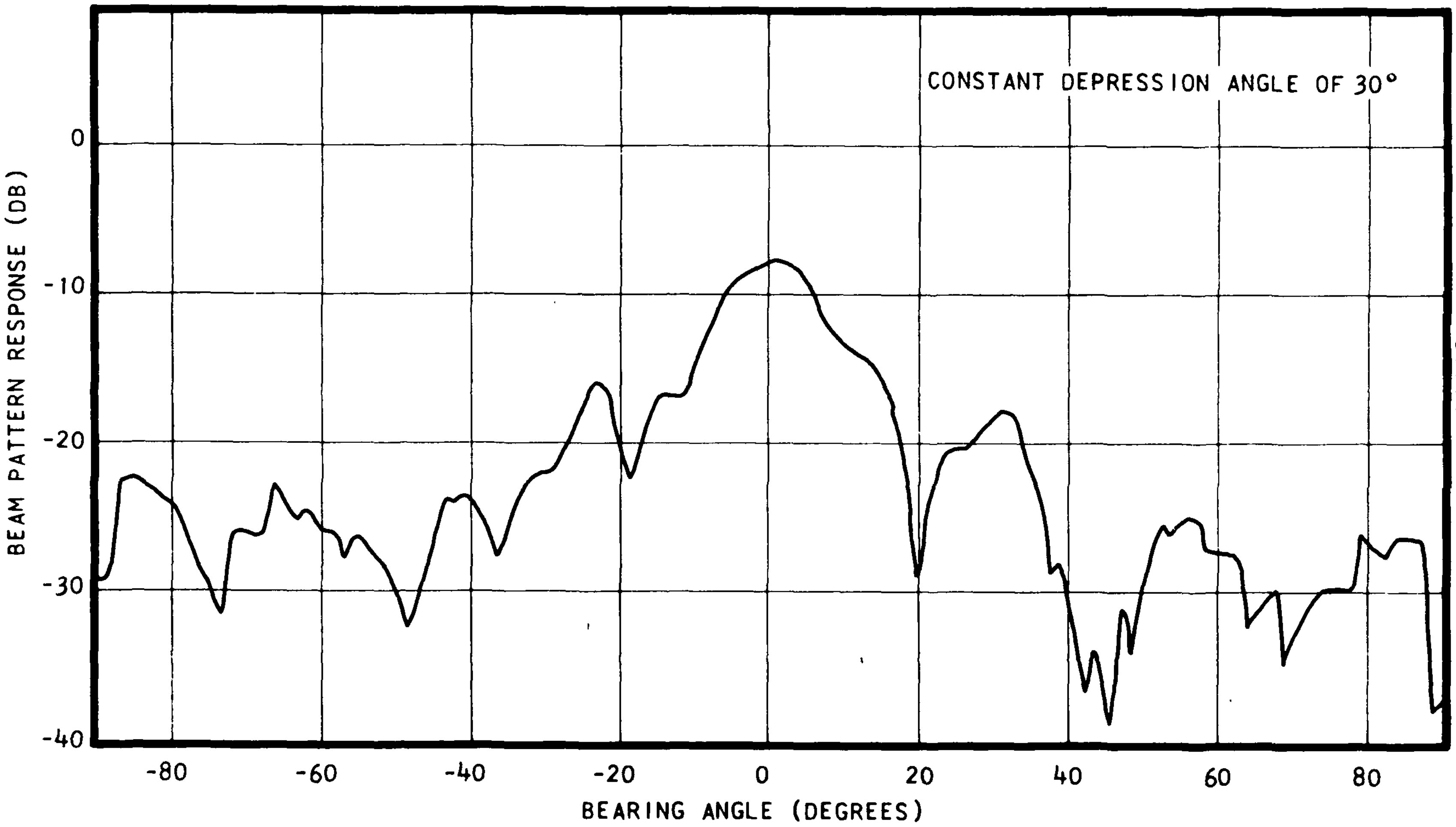


FIG. A-15 - HORIZONTAL SLICE THROUGH 30° DEPRESSED RECEIVE BEAM WITH 51.5% INOPERATIVES

TRACOR, INC. | DWG. A6-13-2148
AUSTIN, TEXAS 5-16-67 Mc ANALLY/S.D.

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Symbol		Power Level (dB)	Symbol		Power Level (dB)
0	=	0	W	=	-32
1	=	-1	X	=	-33
2	=	-2	Y	=	-34
3	=	-3	Z	=	-35
4	=	-4	@	=	-36
5	=	-5	[	=	-37
6	=	-6	]	=	-38
7	=	-7	#	=	-39
8	=	-8	Δ	=	-40
9	=	-9		=	-41
A	=	-10	)	=	-42
B	=	-11	-	=	-43
C	=	-12	+	=	-44
D	=	-13	<	=	-45
E	=	-14	=	=	-46
F	=	-15	>	=	-47
G	=	-16	&	=	-48
H	=	-17	$	=	-49
I	=	-18	*	=	-50
J	=	-19	(	=	-51
K	=	-20	%	=	-52
L	=	-21	:	=	-53
M	=	-22	?	=	-54
N	=	-23	!	=	-55
O	=	-24	,	=	-56
P	=	-25	\	=	-57
Q	=	-26	;	=	-58
R	=	-27	/	=	-59
S	=	-28	'	=	-60
T	=	-29	.	=	-61
U	=	-30	¤	=	-62
V	=	-31			

FIGURE A-16 POWER LEVEL CORRESPONDING TO SYMBOL FOR PRINTED CONTOUR PLOTS

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APPENDIX B

DETAILED REVERBERATION ANALYSIS

This appendix presents more detailed results of the reverberation level analysis. For the wide transmit beam, the model predicts the reverberation for triple ping, and any number of receive positions. To avoid the complexity of using all possible receive positions only five representative positions were used. Figure B-1 shows the relative locations of the transmit and receive positions. The multiple positions are not an exact representation when element failures occur, since the same array is assumed at each position. For example, consider an array of seven transducers as shown in Fig.B-2. Suppose that for a given transmit or receive sequence, only three elements are used (i.e., for position No.1 elements 1,2, and 3 are used; for position No.2 elements 3,4,5 are used, etc.). If elements 1,4, and 7 fail, then at each position, a different array is encountered. At position No.1, only elements 2 and 3 are now operating, at position No.2 elements 3 and 5 are operating, and at position No.3 elements 5 and 6 are operating. Therefore, at each position a different array is encountered, but the reverberation model does not take this into account and considers the same array at each position even though certain failures have occurred.

The reverberation level is considered as a function of time after transmission and dependent on such parameters as beam patterns, depth, wind speed, etc. The model is essentially the same as that described in a previous report[1].

To determine the signal level decrease, the source level at each receive position is determined from the transmit beam

[1] Fowler, Steve, "Bottom Bounce Reverberation Model and Bottom Loss Analysis (U)", TRACOR, Inc., Tech. Memo. 66-355-C, Contract NObsr-93140, 16 November 1966 (Confidential).

pattern, and the signal loss encountered due to the decrease in the level of the receive beam pattern. Table B-I shows the source level for the transmit pattern at each receive position, the signal loss due to the receive pattern, and the total signal loss for each percentage of inoperatives. The total signal loss in dB is added to the change in reverberation level, and the decrease in the signal-to-noise ratio thus obtained.

Figures B-3 through B-26 show the total reverberation level and the decrease in signal-to-noise ratio as a function of time after transmission for each of the different depths, wind speeds, and numbers of element failures.

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TABLE B-I

SIGNAL LEVEL DECREASE FOR EACH RECEIVE POSITION

IRC*	30° DEPRESS. WIDE XMIT SIGNAL LEVEL			20° DEPRESS. WIDE XMIT SIGNAL LEVEL			
	0%	31.8%	51.8%	0%	25%	31.8%	51.5%
1	35.635	31.708	26.258	35.762	32.489	33.324	25.672
2	34.427	32.604	28.017	35.803	31.963	33.193	29.578
3	35.635	31.708	26.258	35.762	32.489	33.324	25.672
4	34.427	31.622	28.340	35.803	34.137	33.706	30.134
5	35.635	32.980	29.417	35.762	33.713	31.796	29.547

30° REC. SIG. LEVEL DECREASE		20° REC. SIG. LEVEL DECREASE		
31.8%	51.5%	25%	31.8%	51.5%
3.117	7.413	2.300	3.260	7.092

TOTAL SIGNAL LEVEL DECREASE

	30°		20°		
IRC*	31.8%	51.5%	25%	31.8%	51.5%
1	3.927	16.790	5.573	5.698	17.182
2	4.940	13.823	6.140	5.870	13.317
3	3.927	16.790	5.573	5.698	17.182
4	5.922	13.500	3.966	5.337	12.761
5	5.772	13.631	4.349	7.226	13.307

* NOTE: IRC - Receive Position Number

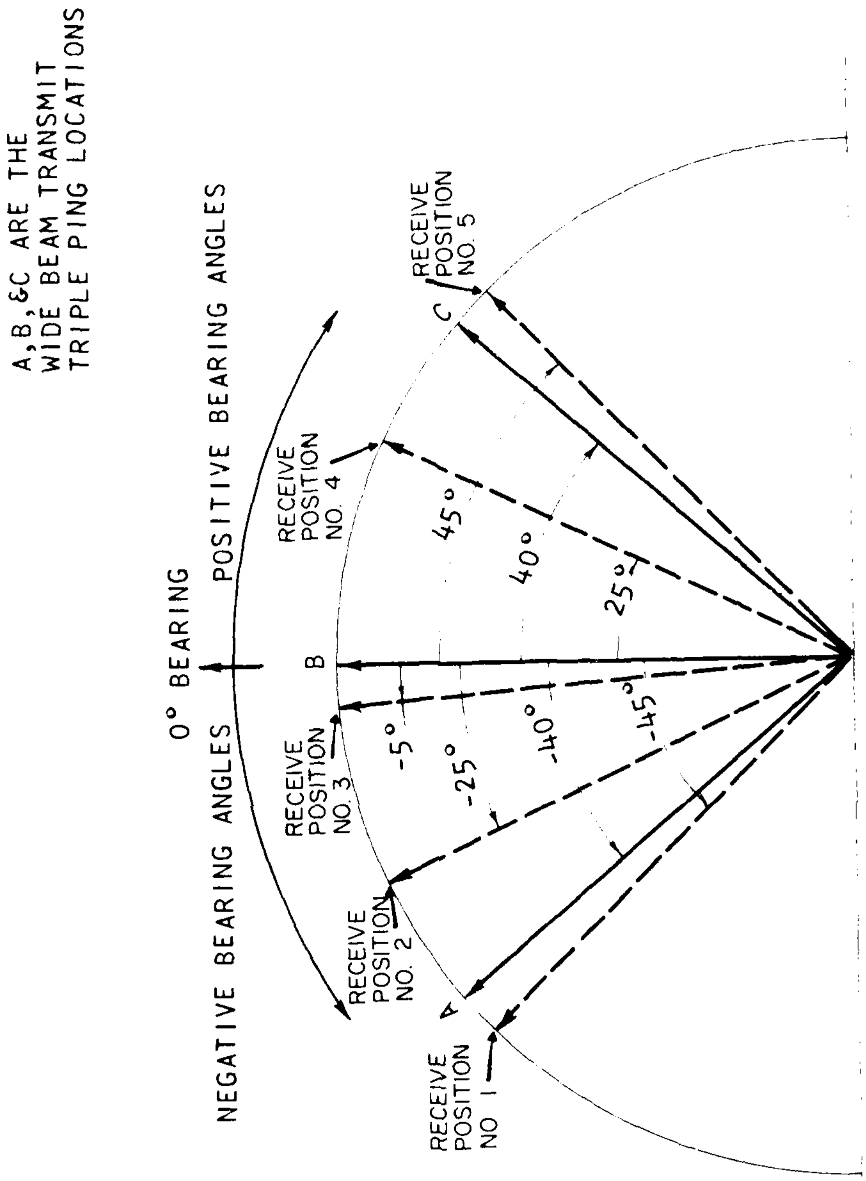

FIG. B-1 - RELATIVE LOCATION OF TRANSMIT AND RECEIVE POSITIONS FOR WIDE BEAM, TRIPLE PING TRANSMIT AND FIVE RECEIVE POSITIONS

TRACOR, INC DWG A6-13-2103
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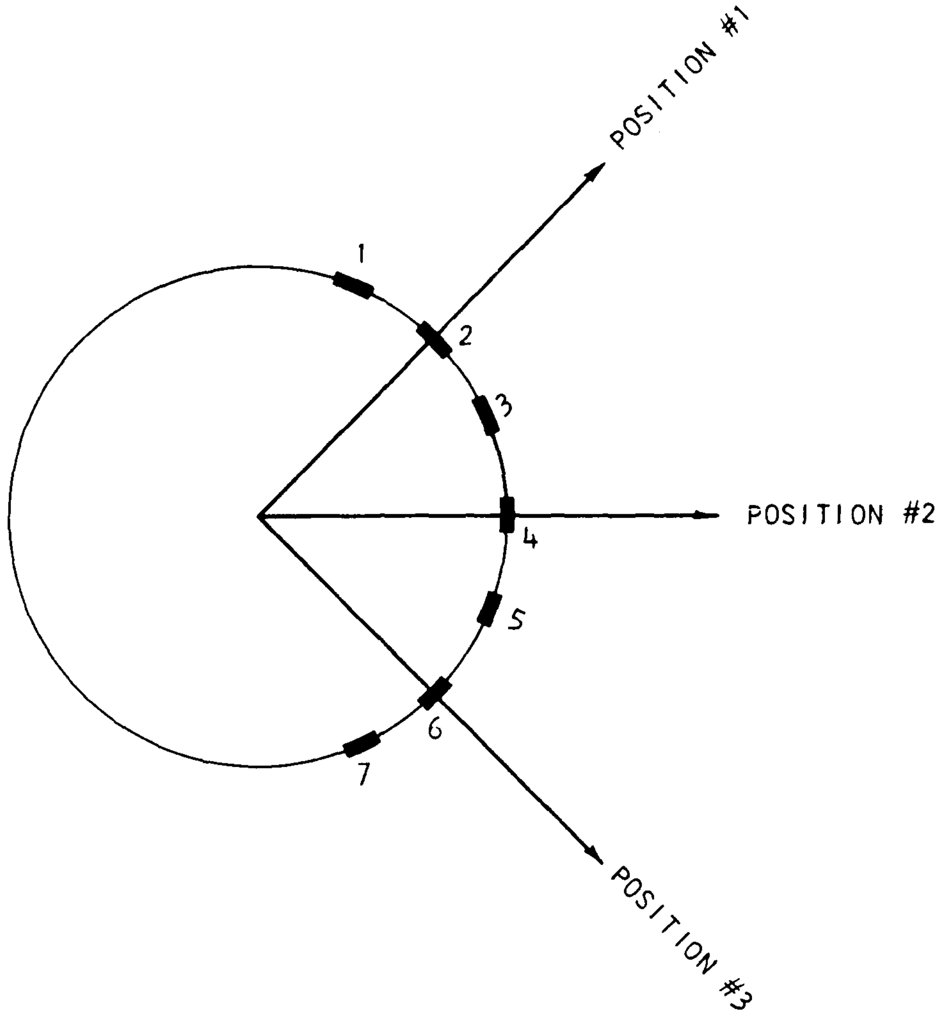

FIG. B-2 - EXAMPLE TRANSDUCER ARRAY

TRACOR, INC DWG A6-13-2102
AUSTIN, TEXAS 5-16-67 McANALLY/S.L.

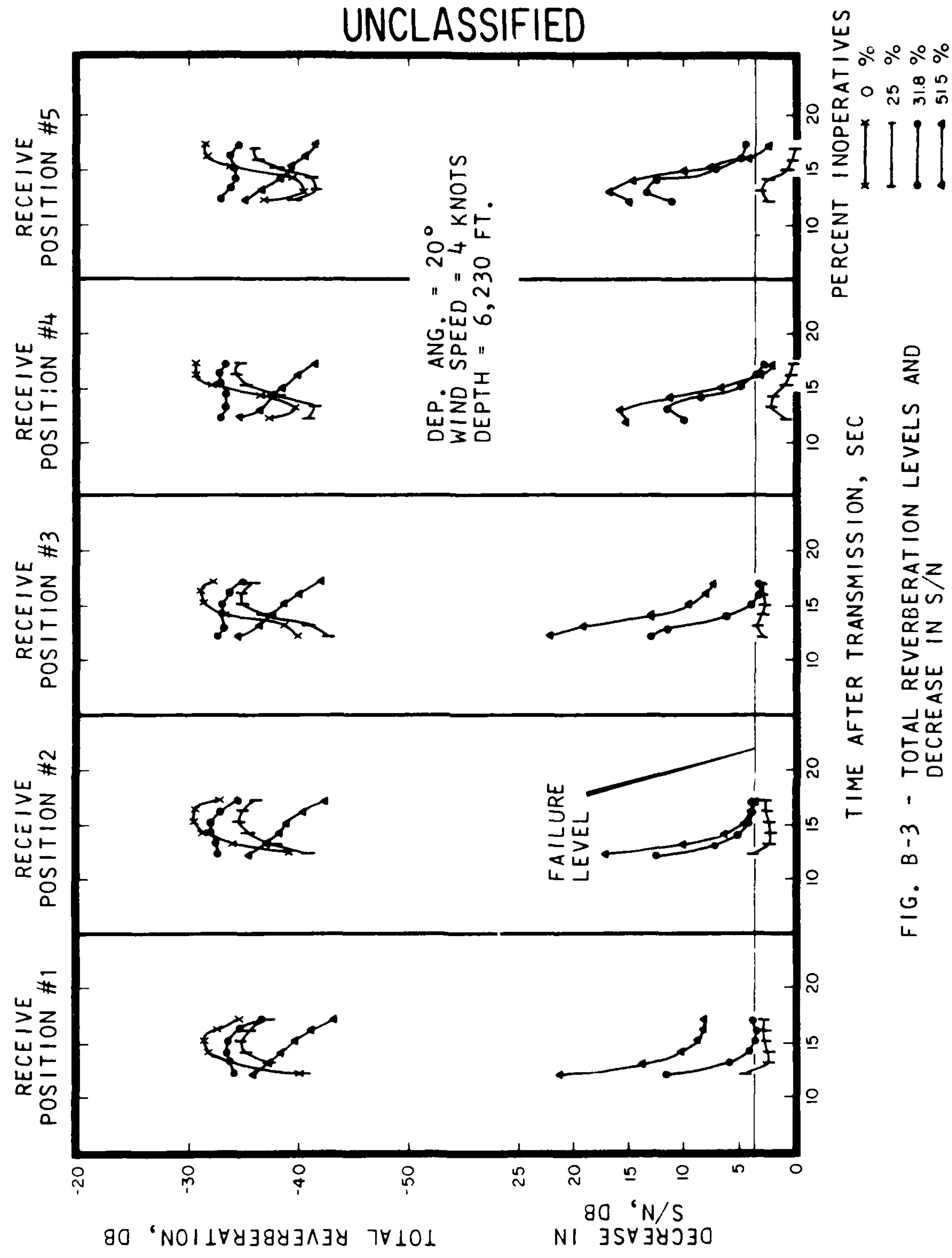

FIG. B-3 - TOTAL REVERBERATION LEVELS AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2111
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

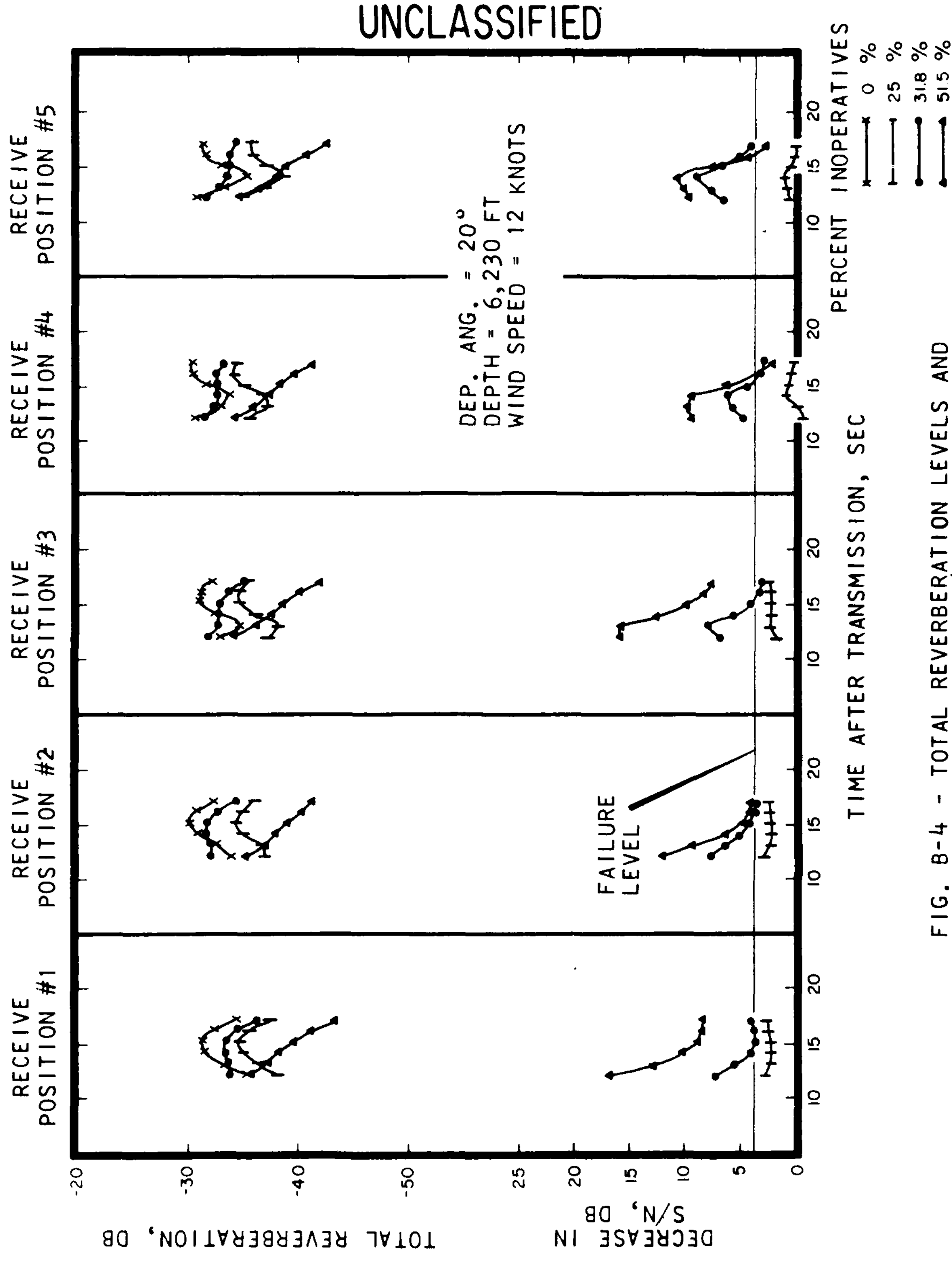

FIG. B-4 - TOTAL REVERBERATION LEVELS AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2112
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

UNCLASSIFIED

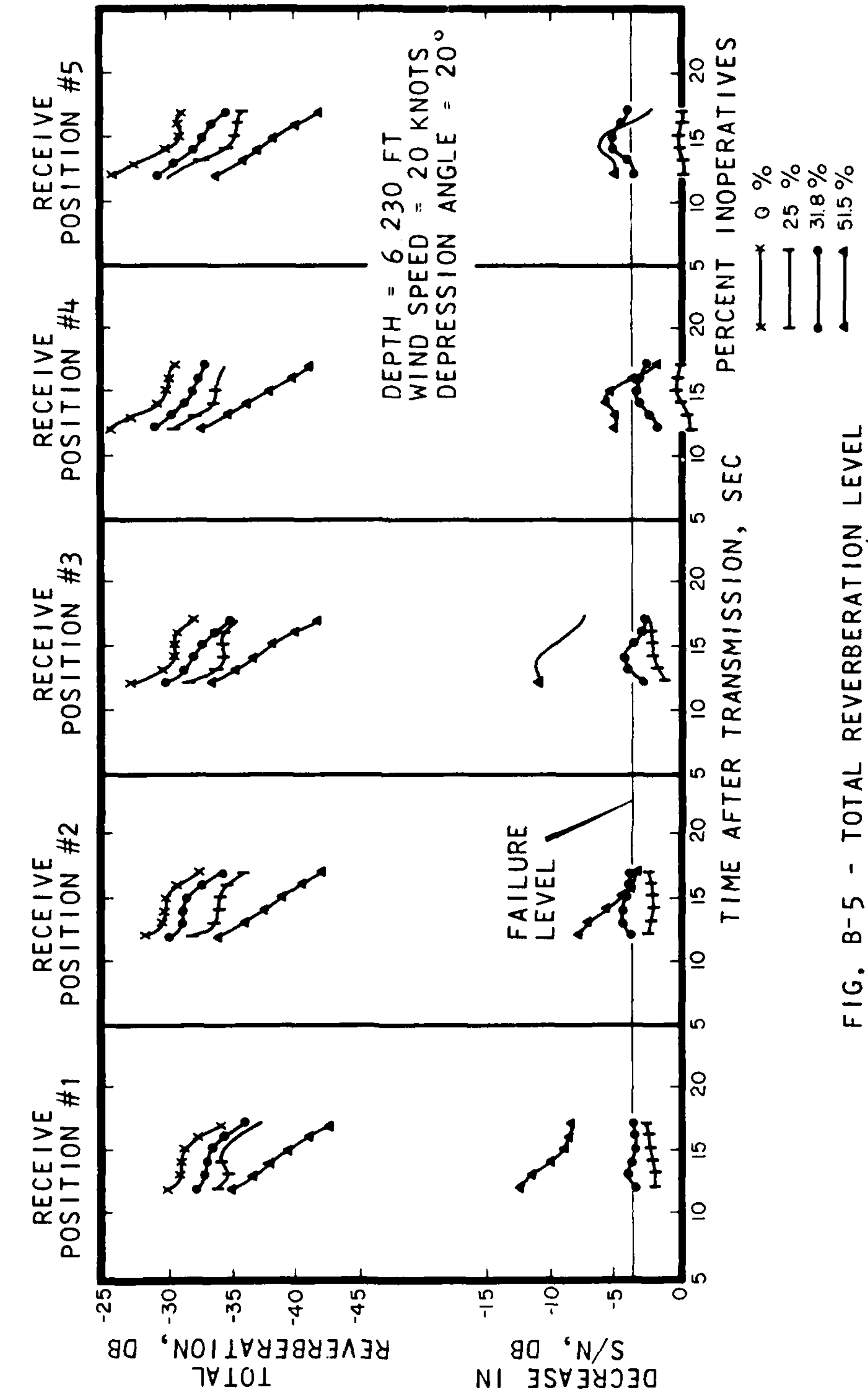

FIG. B-5 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-211
AUSTIN, TEXAS 5-16-67 McANALLY / S.

UNCLASSIFIED

UNCLASSIFIED

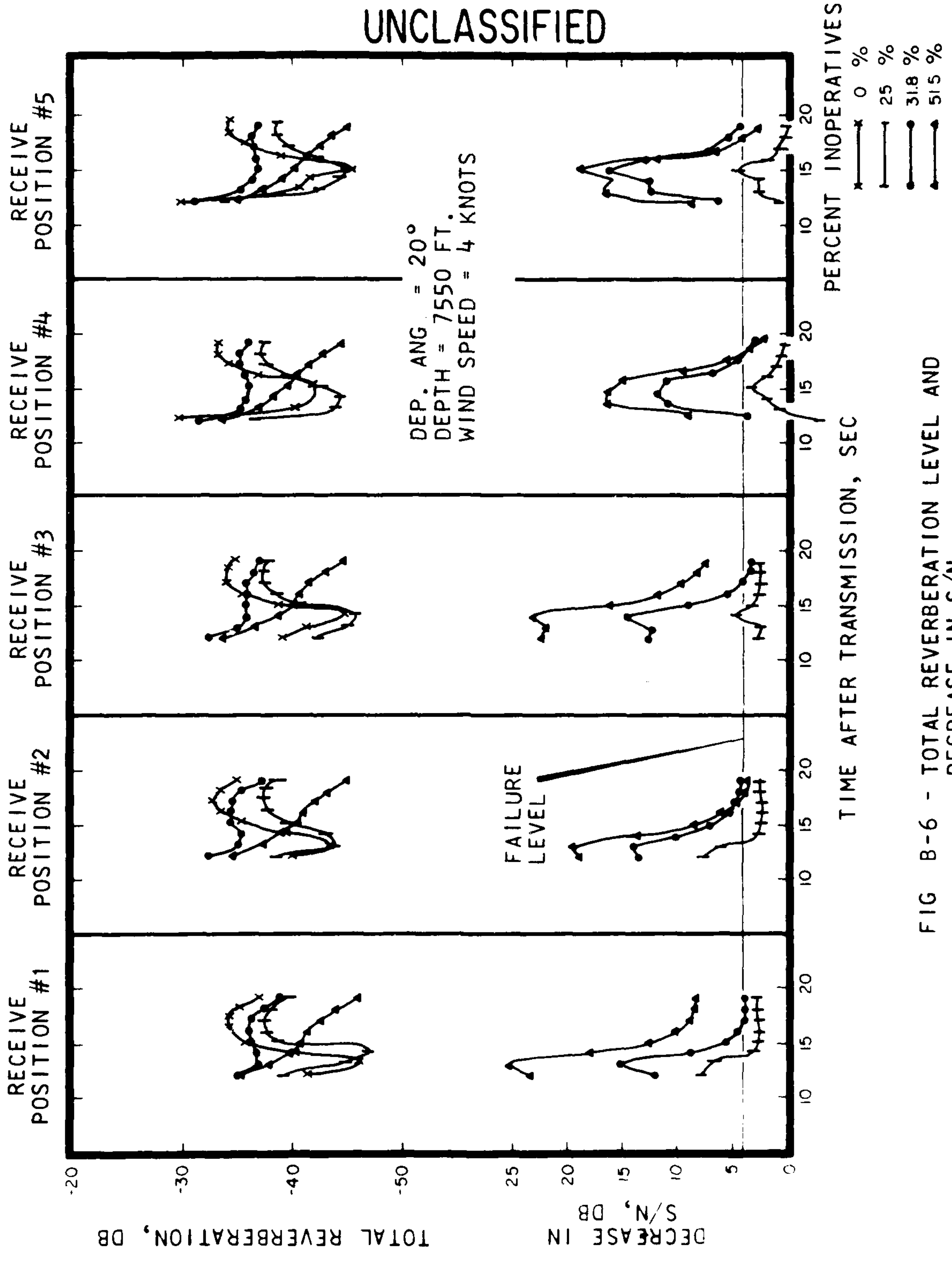

FIG B-6 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N.

UNCLASSIFIED

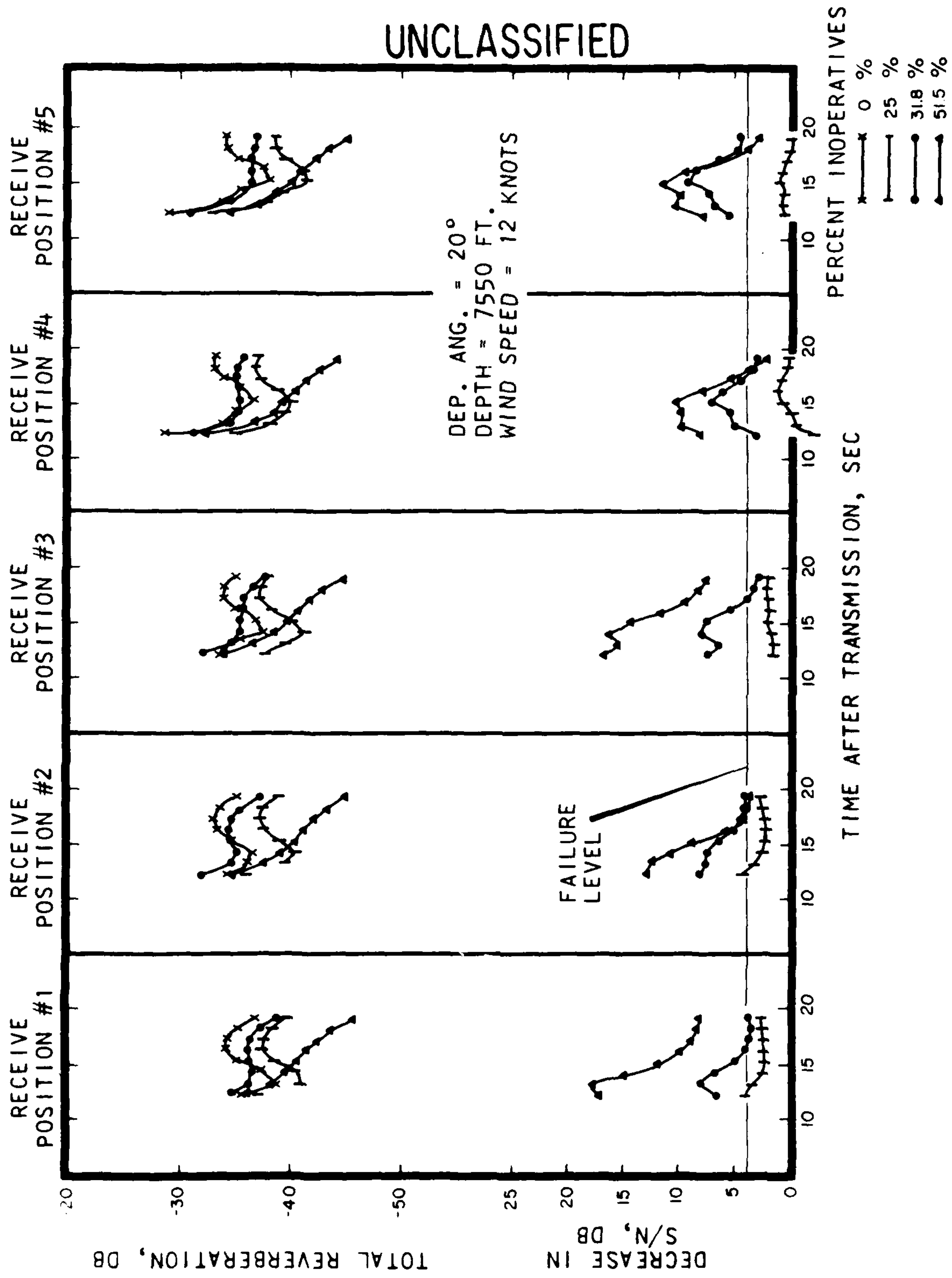

FIG. B-7 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2115
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

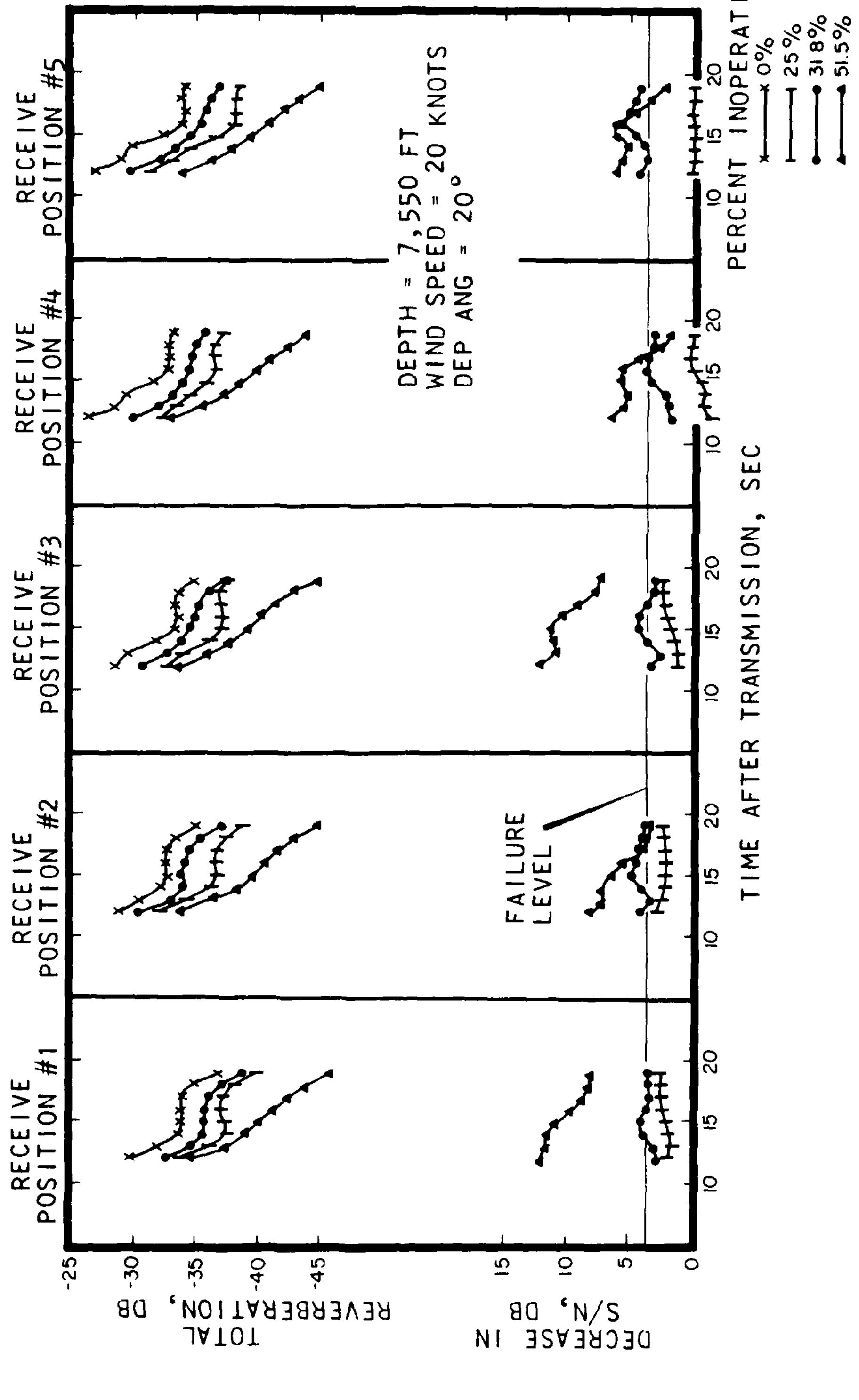

FIG. B-8 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2116
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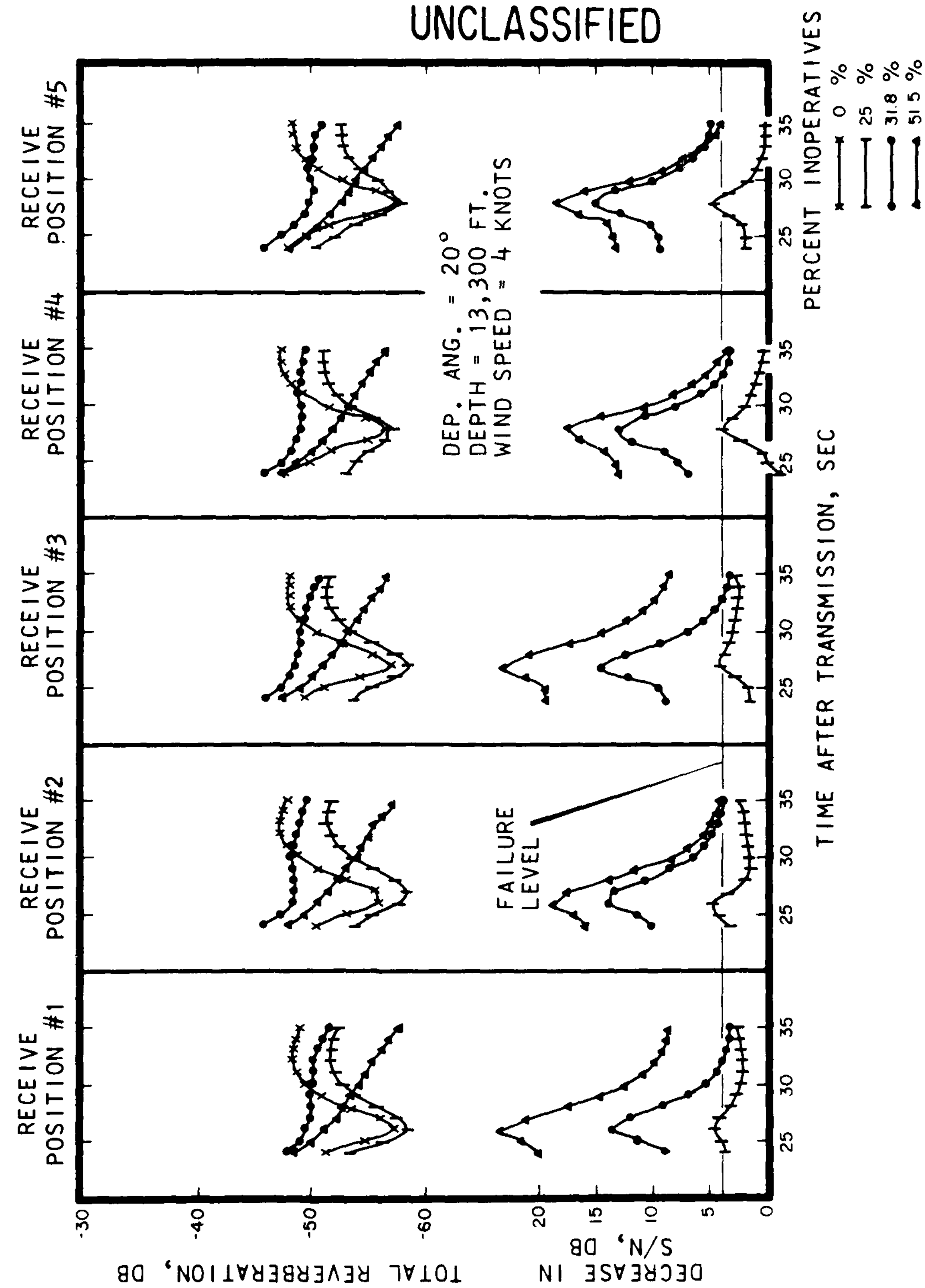

FIG. B-9 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2117
AUSTIN, TEXAS 5-16-67 Mc ANALLY/S.D.

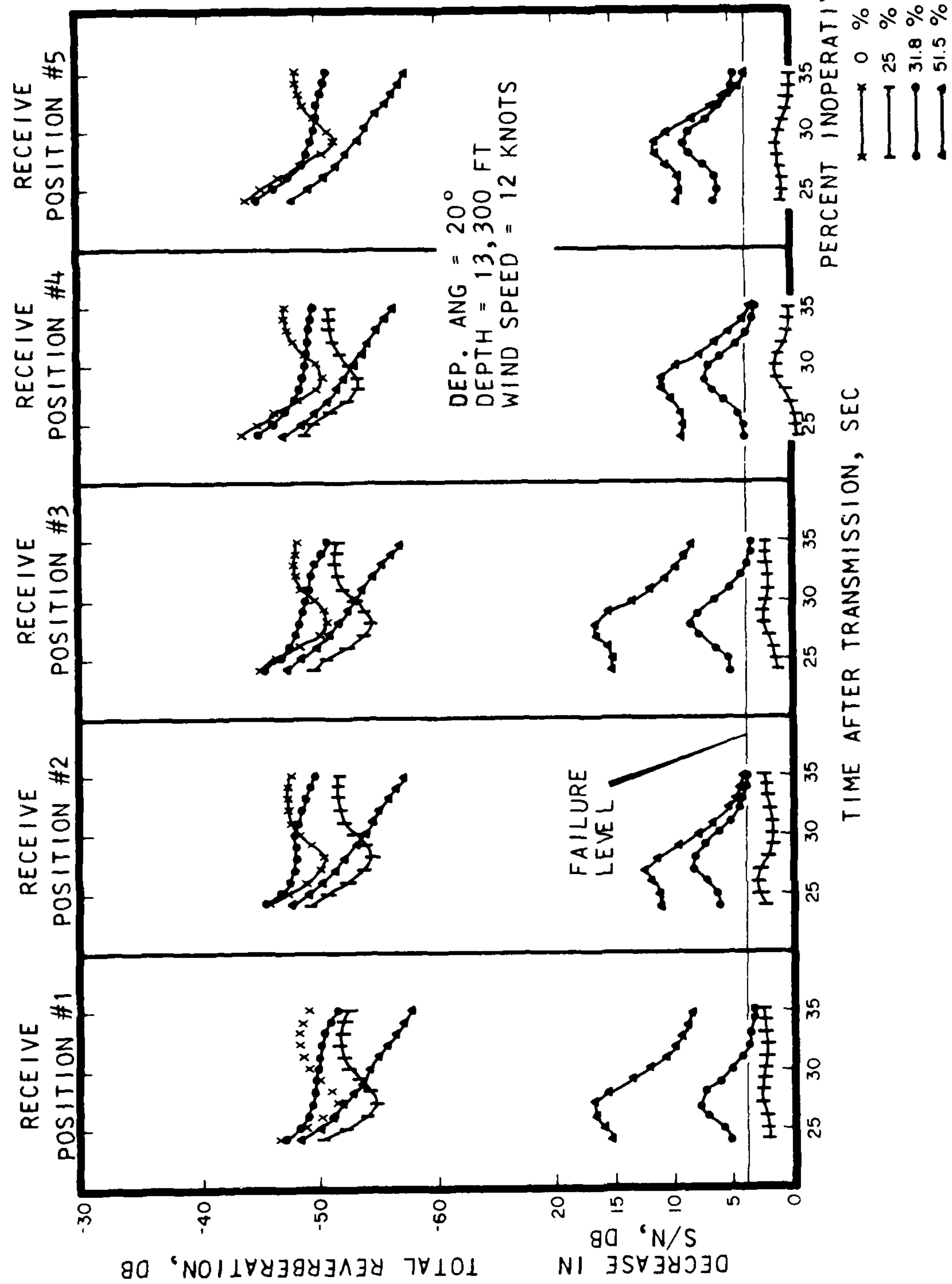

FIG. B-10 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2118
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

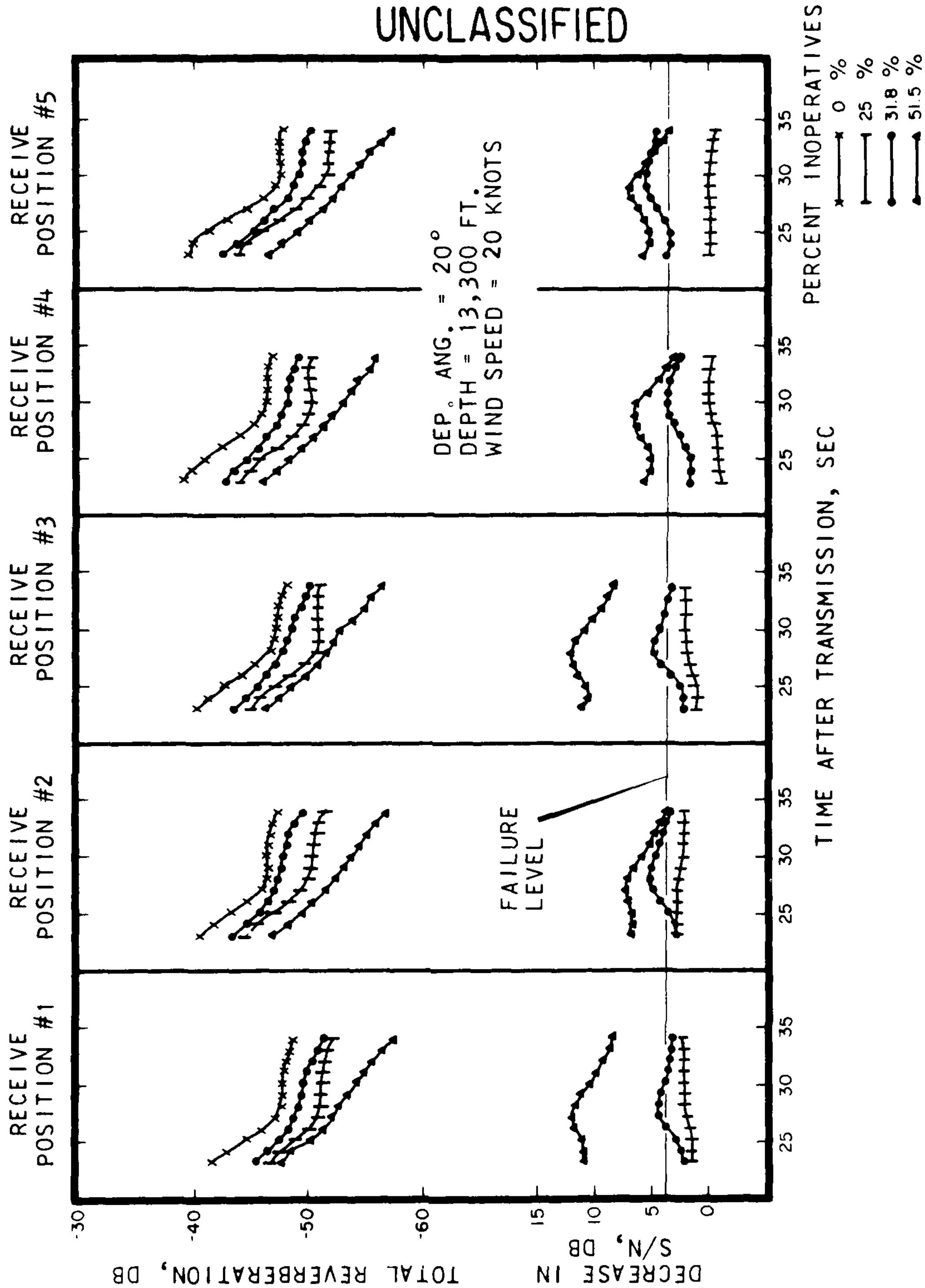

FIG. B-11 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2119
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

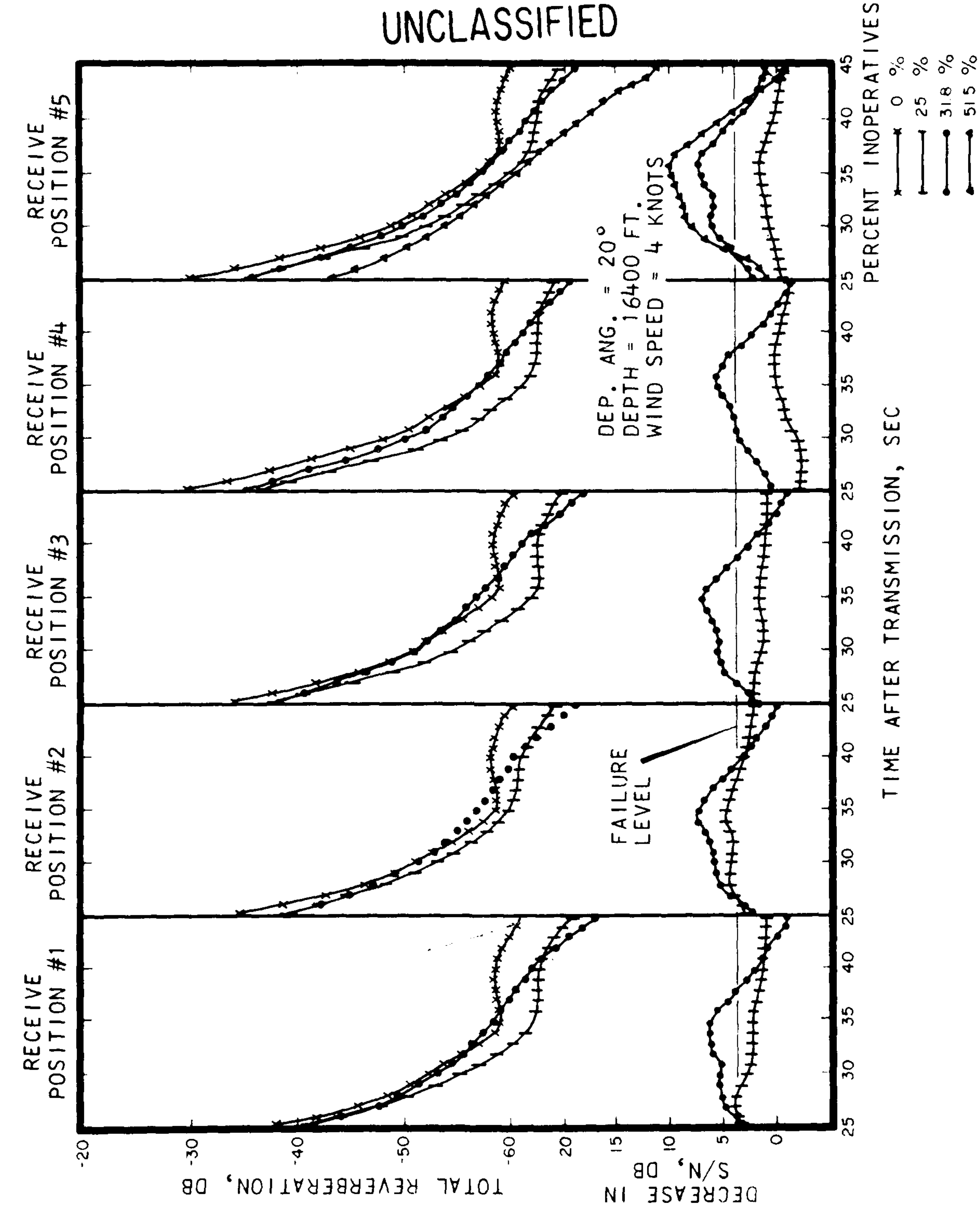

FIG. B-12 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC. DWG A6-13-2120
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

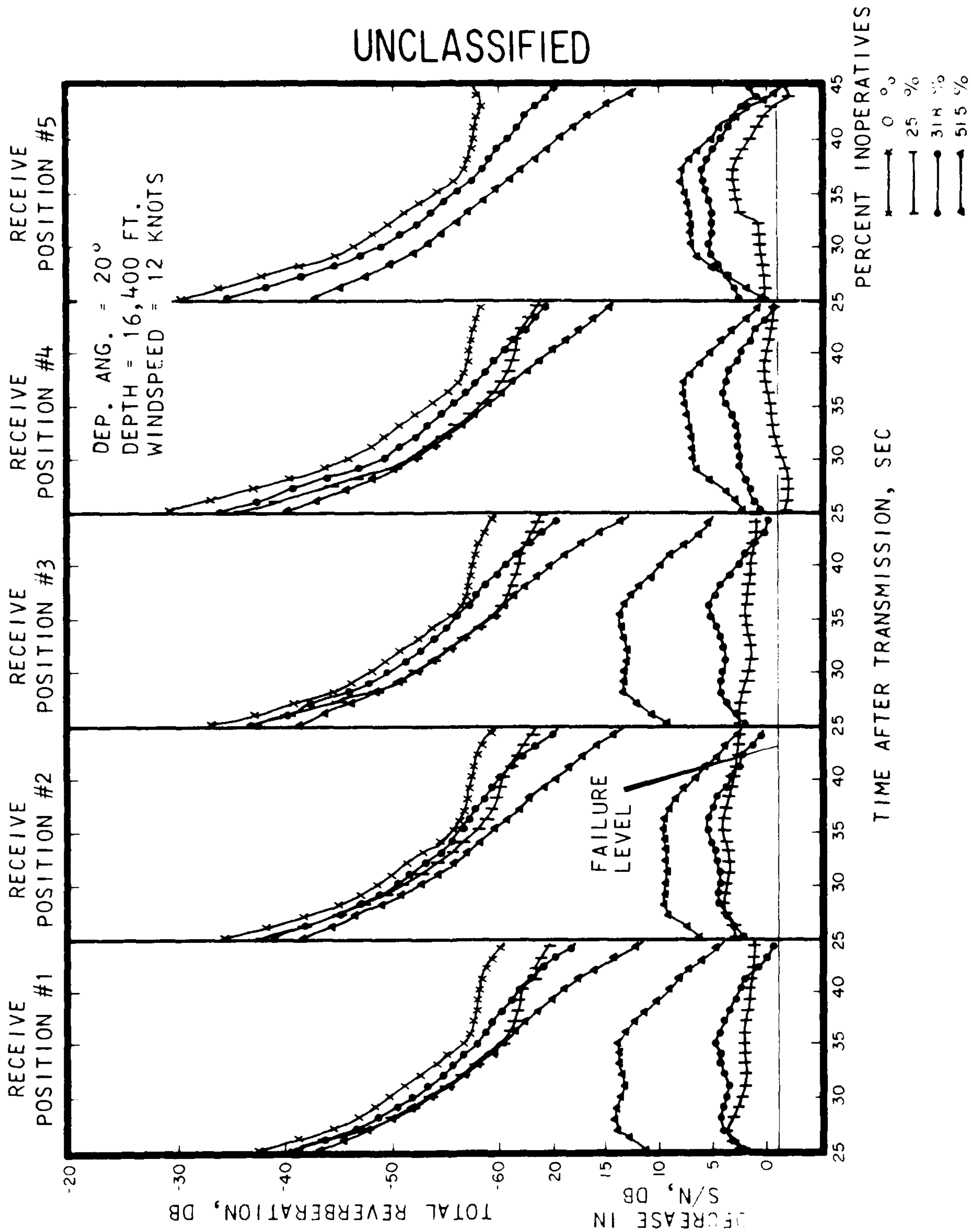

FIG. B-13 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR INC DWG A6-13-2121
AUSTIN, TEXAS 5-16-67 McANALLY/S.D.

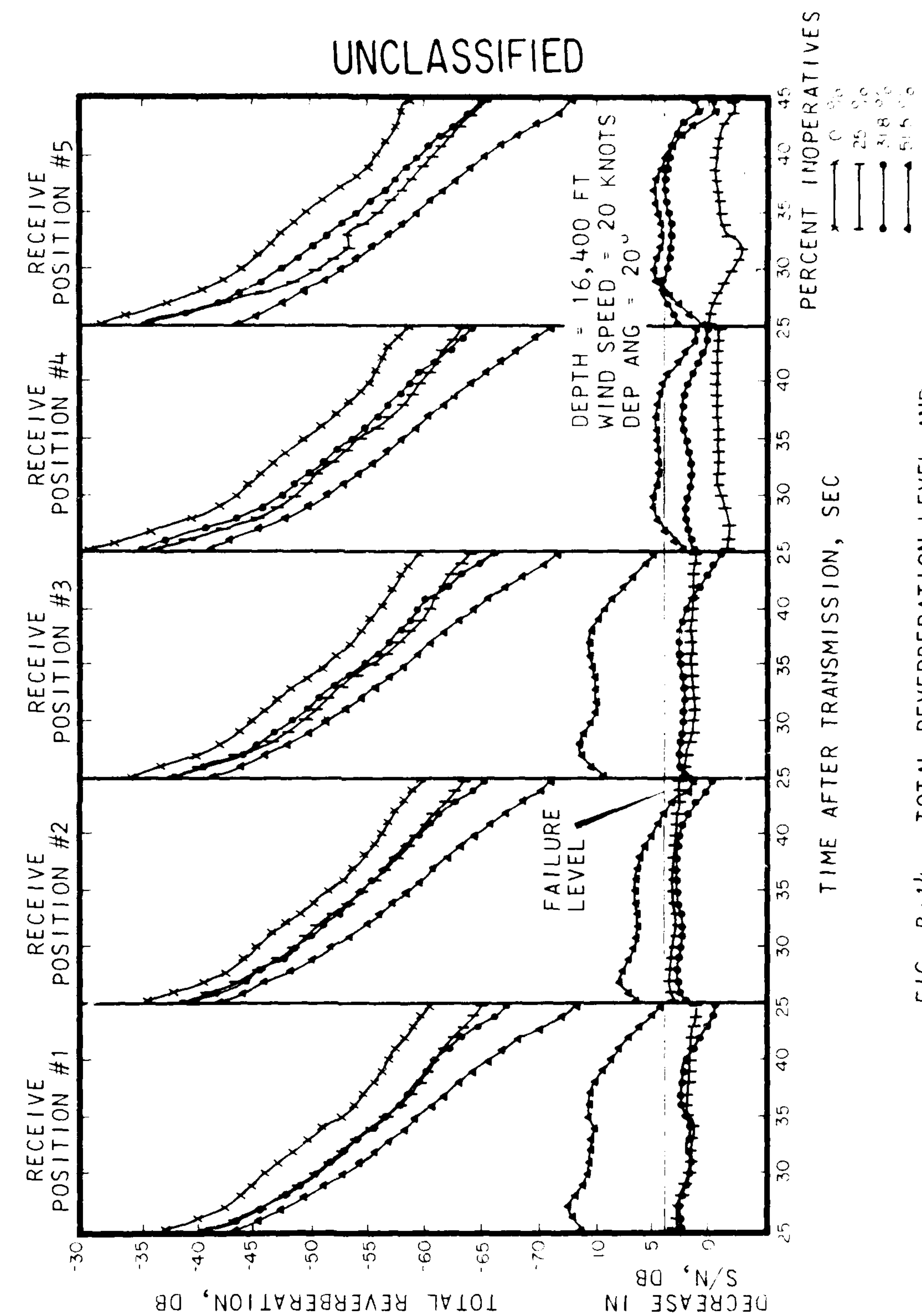

FIG. B-14 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC
AUSTIN, TEXAS 5-16-67

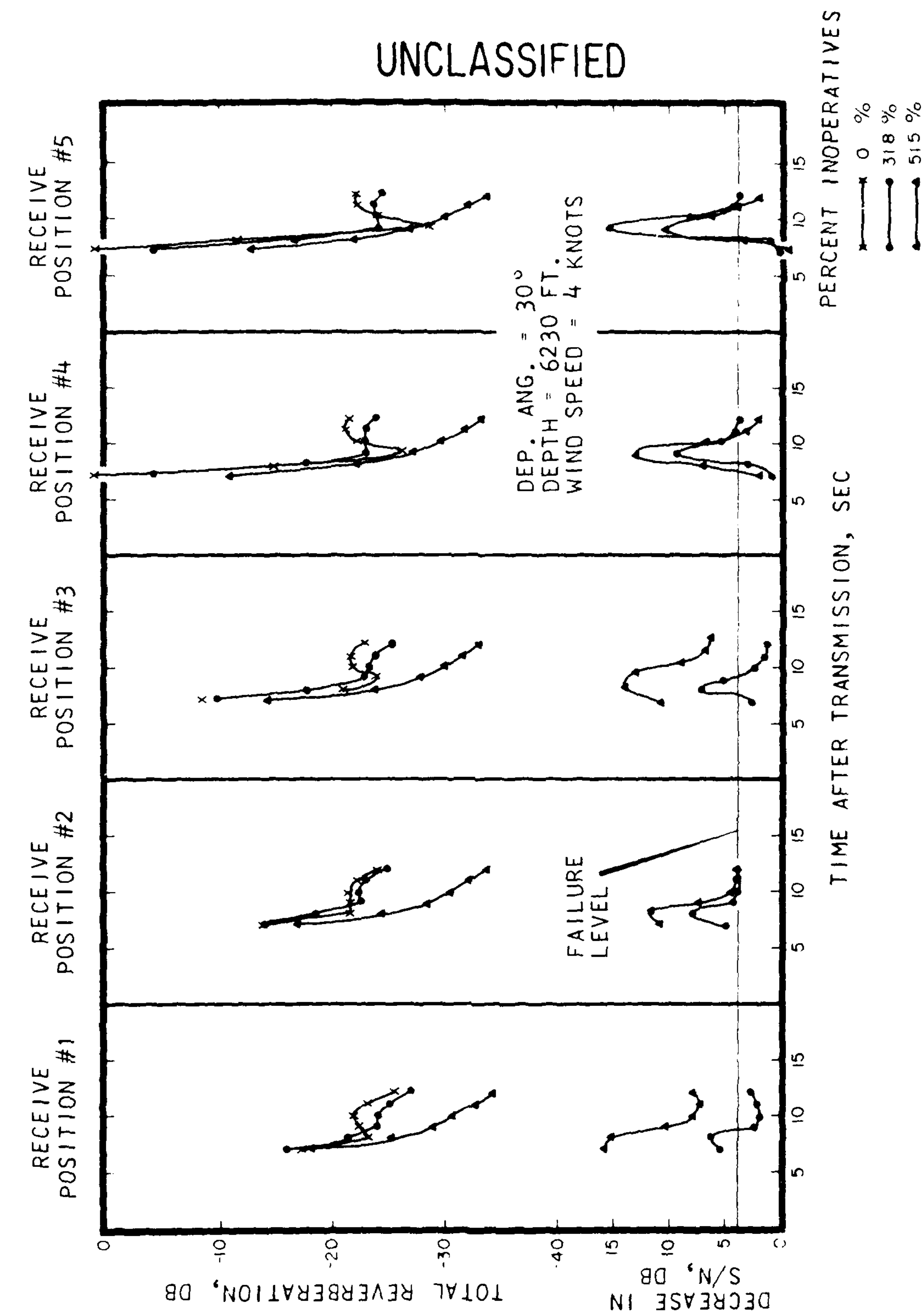

FIG. B-15 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2123
AUSTIN, TEXAS 5-16-67 McANALLY/ S.D.

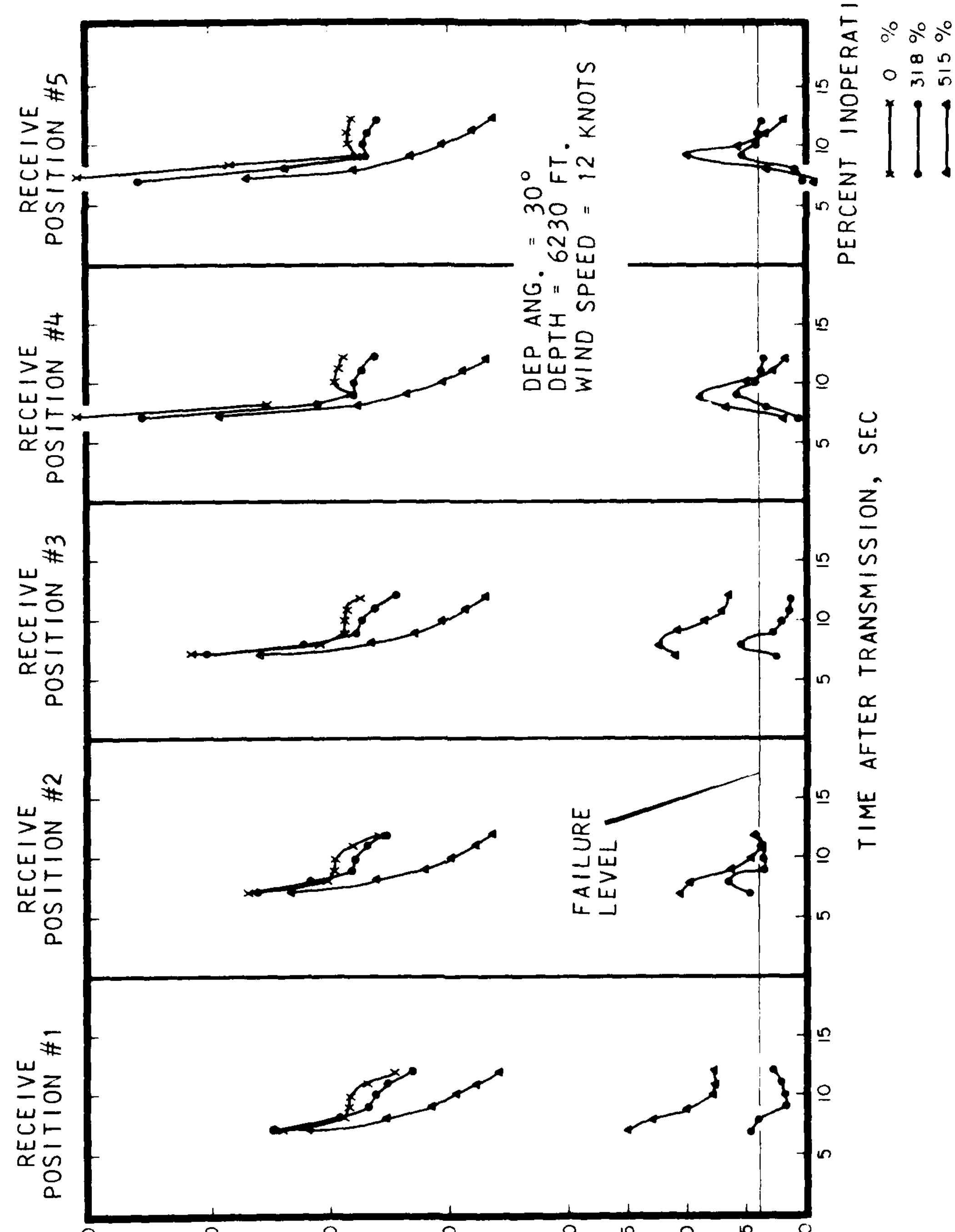

FIG. B-16 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2
AUSTIN, TEXAS 5-16-67 Mc ANALLY/?

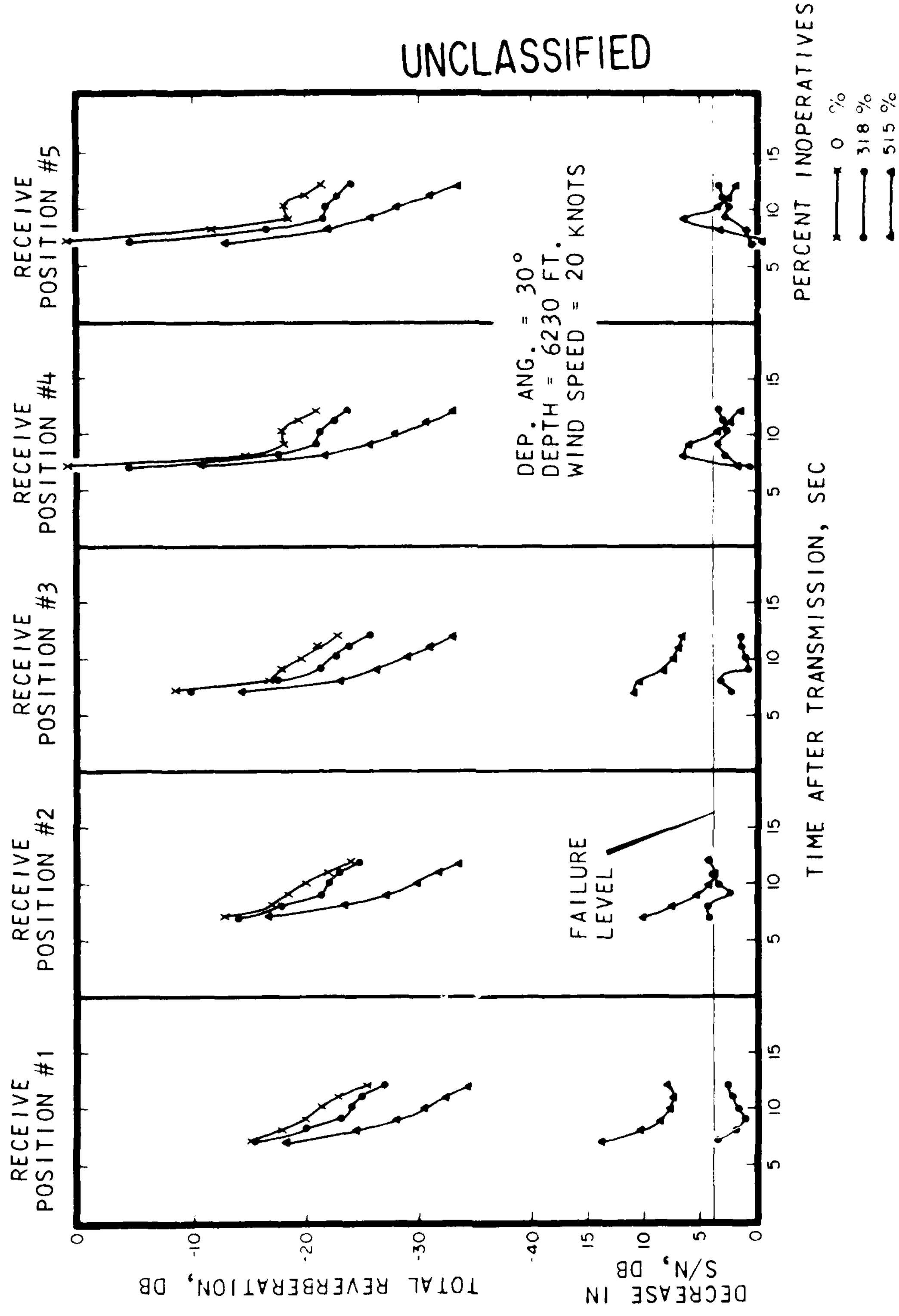

FIG. B-17 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2125
AUSTIN, TEXAS 5-16-67 McANALLY/S.D

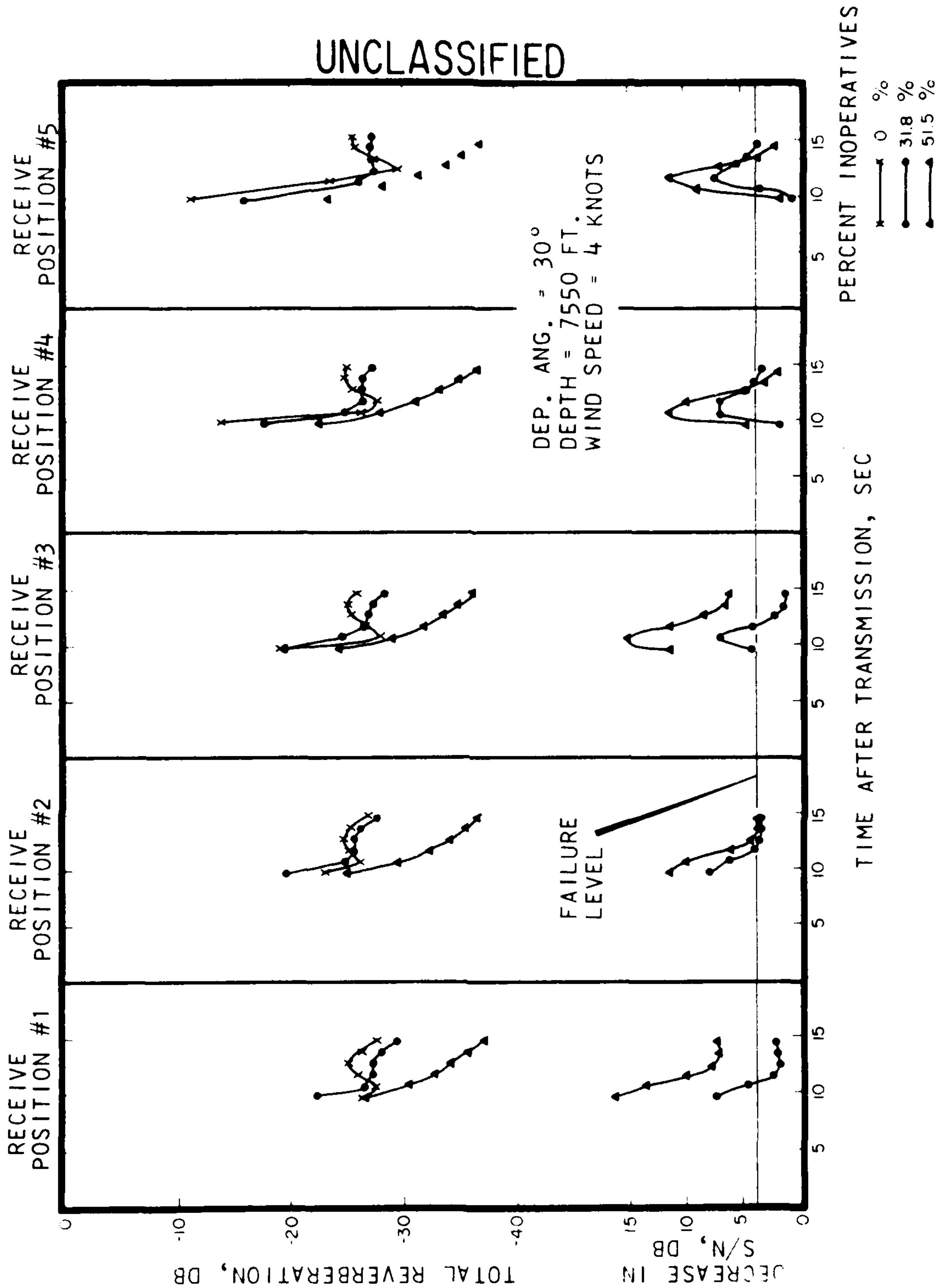

FIG. B-18 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC. AUSTIN TEXAS 5-16-67 DWG A6-13-2126 McANALLY/S.D.

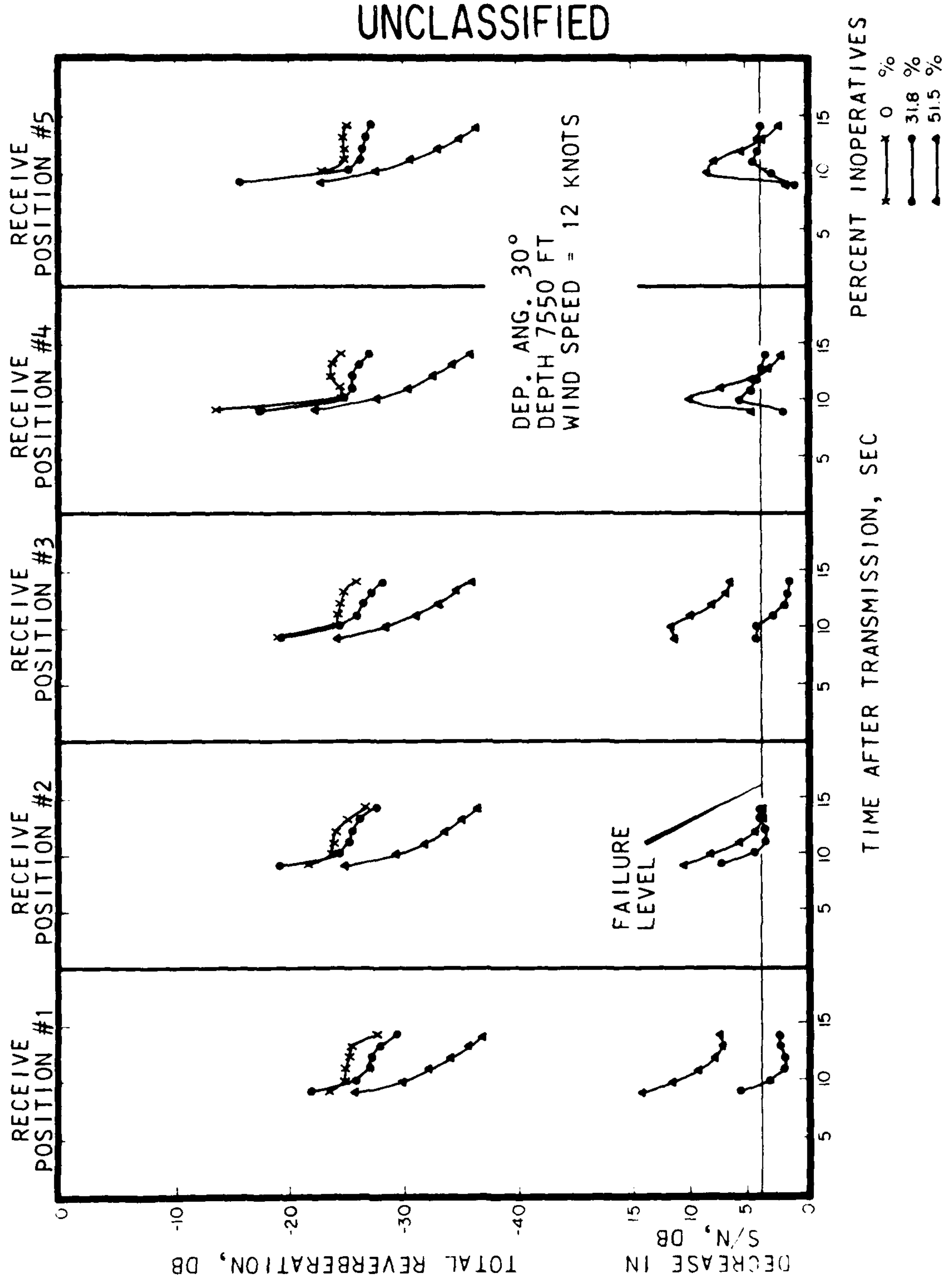

FIG. B-19 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR INC DWG A6-13-2127
AUSTIN TEXAS 5-16-67 McANALLY/S.D.

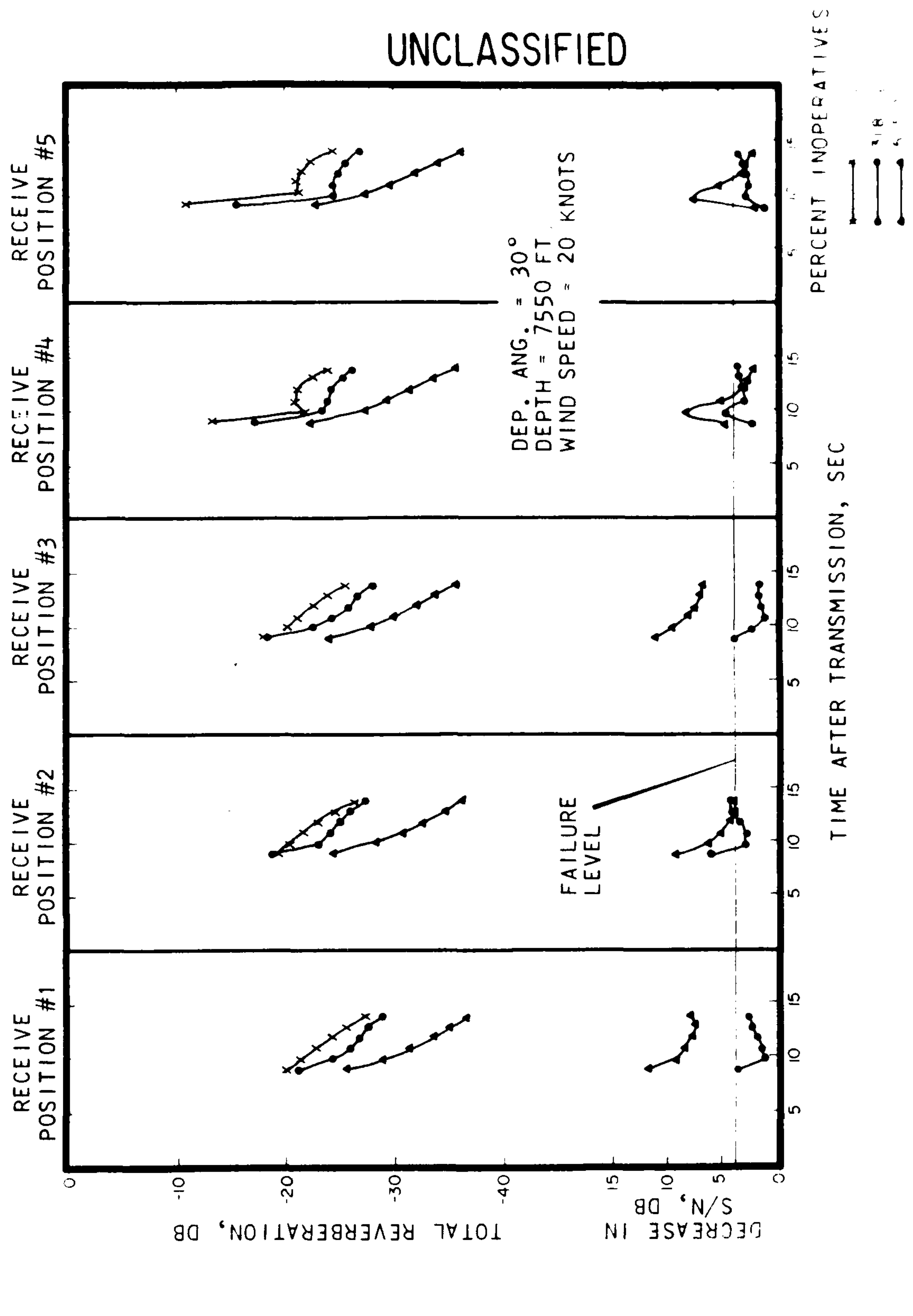

FIG. B-20 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC. AUSTIN, TEXAS 5-16-67 DWG A6-13-2128 McANALLY/S.D.

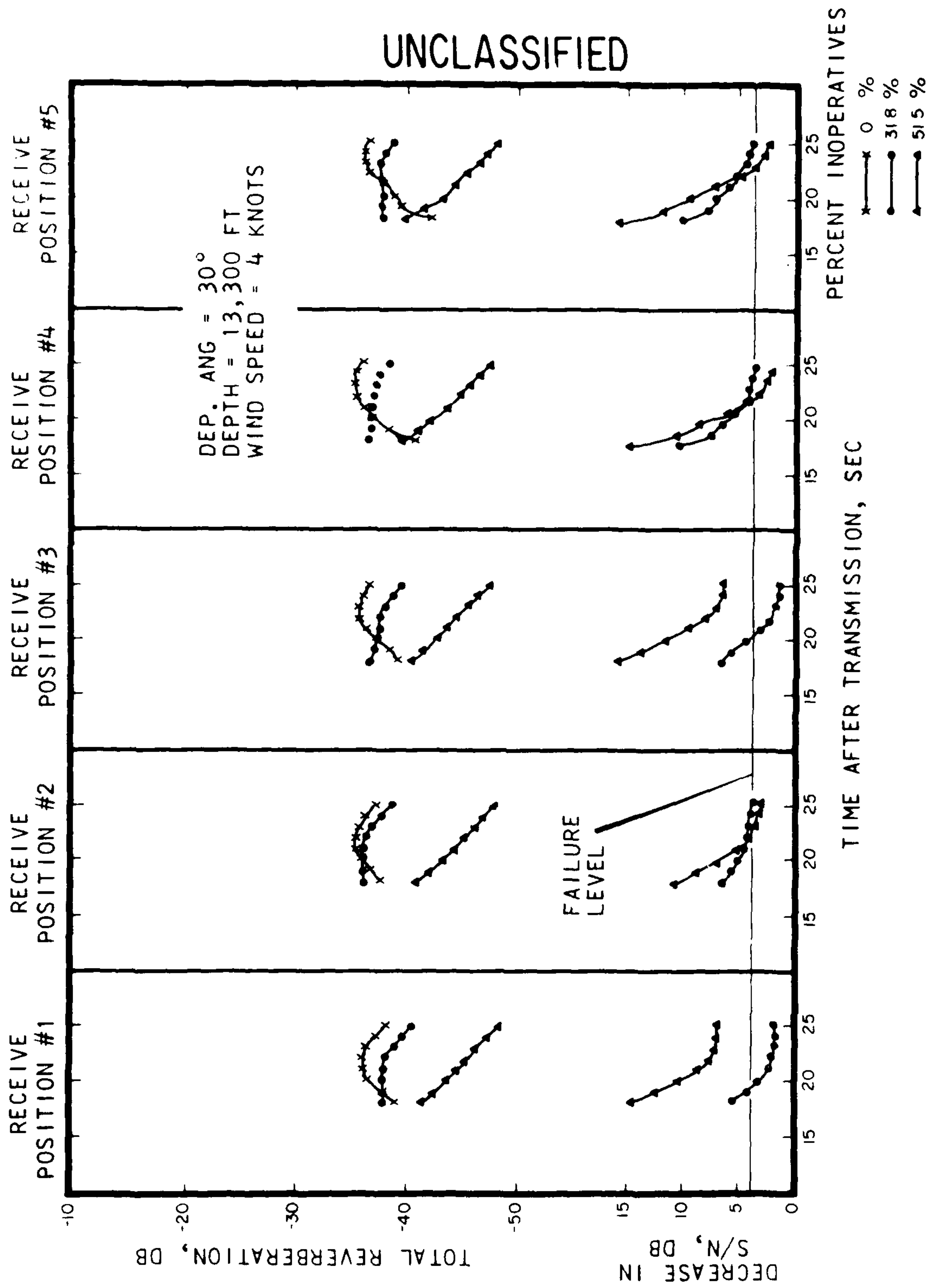

FIG. B-21 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC — AUSTIN, TEXAS 5-16-67 — DWG A6-13-2129 — McANALLY/S.D.

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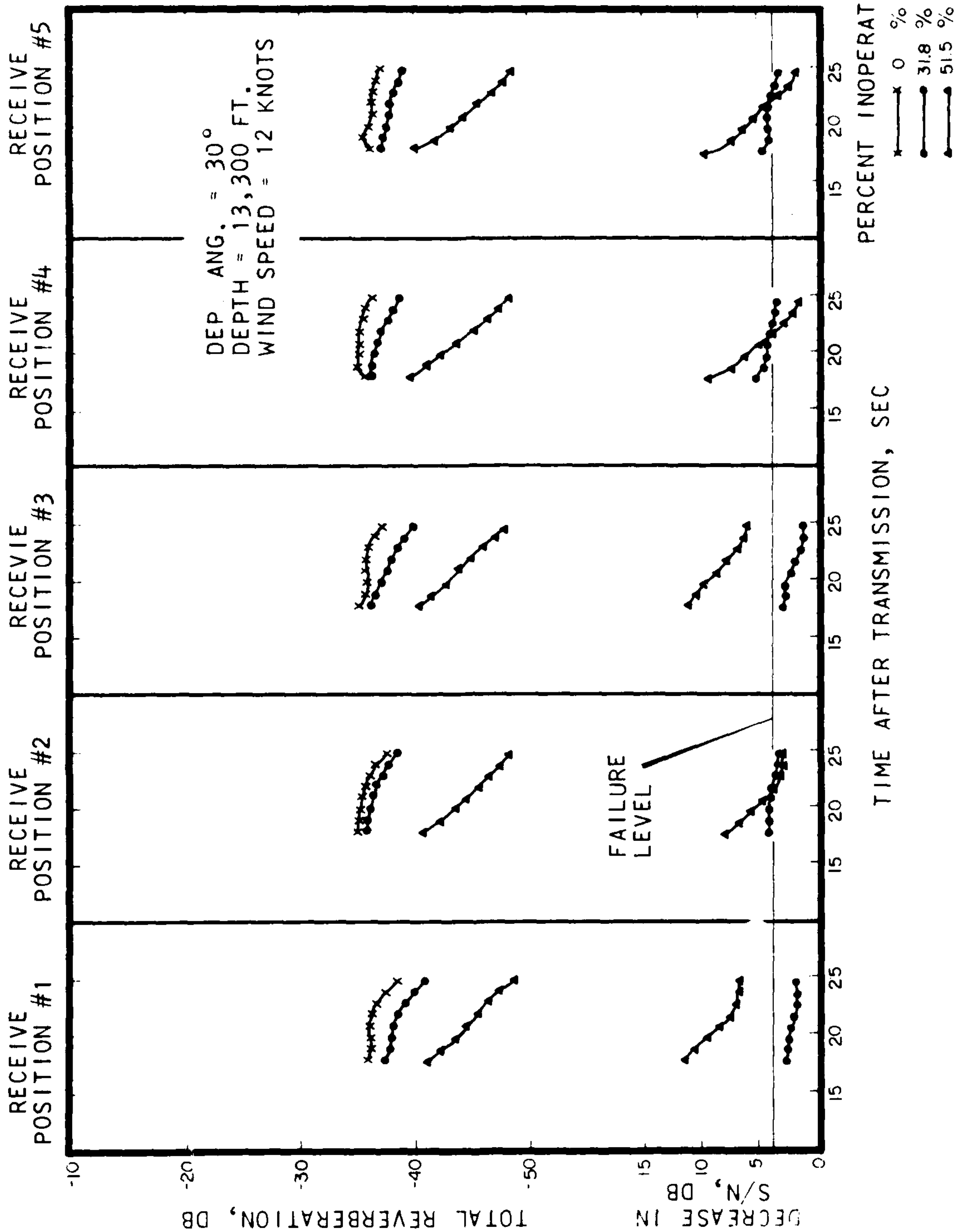

FIG. B-22 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-213
AUSTIN TEXAS 5-16-67 McANALLY/S.

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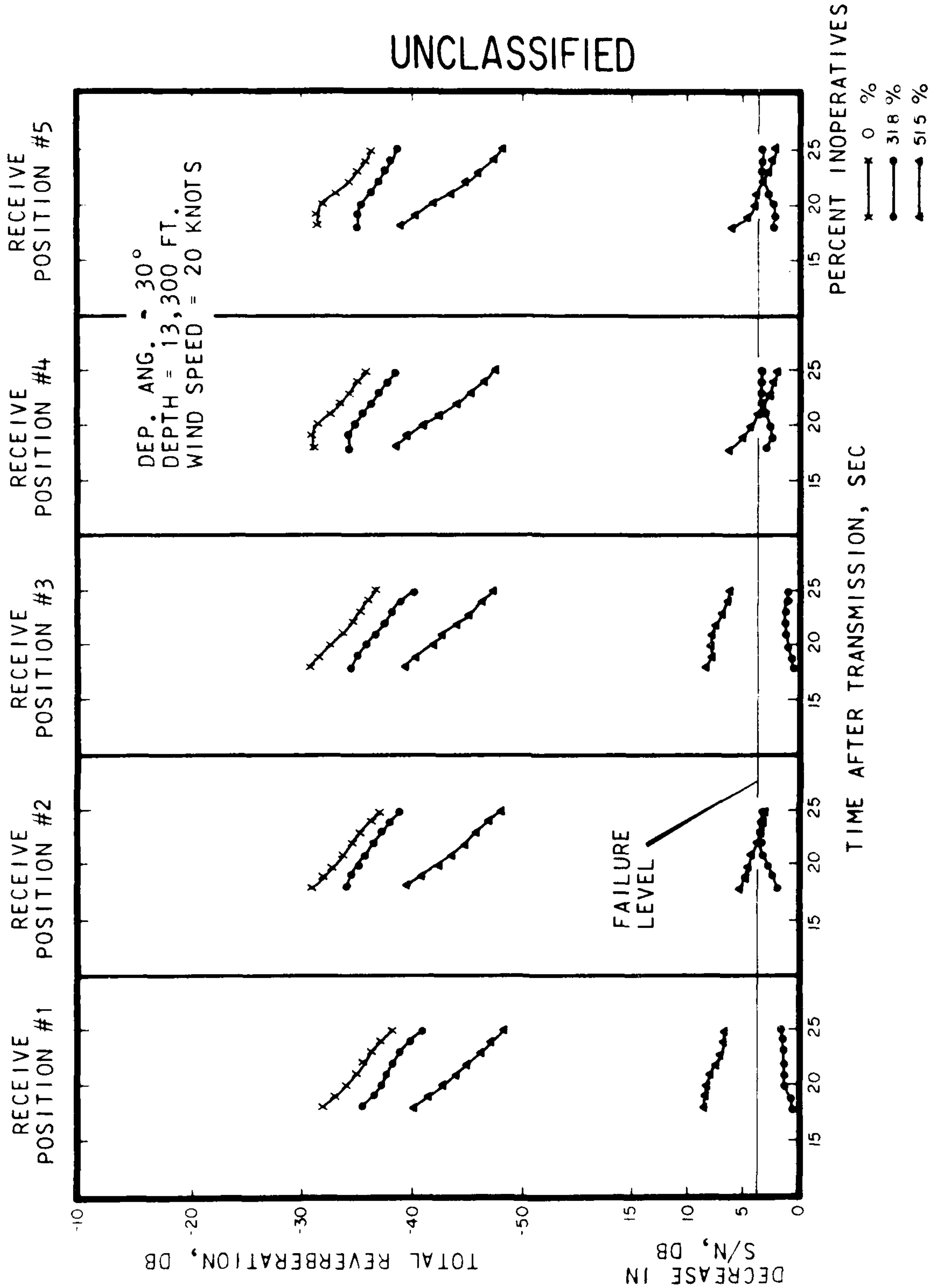

FIG B-23 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2131
AUSTIN, TEXAS 5-16-67 Mc ANALLY / S.D.

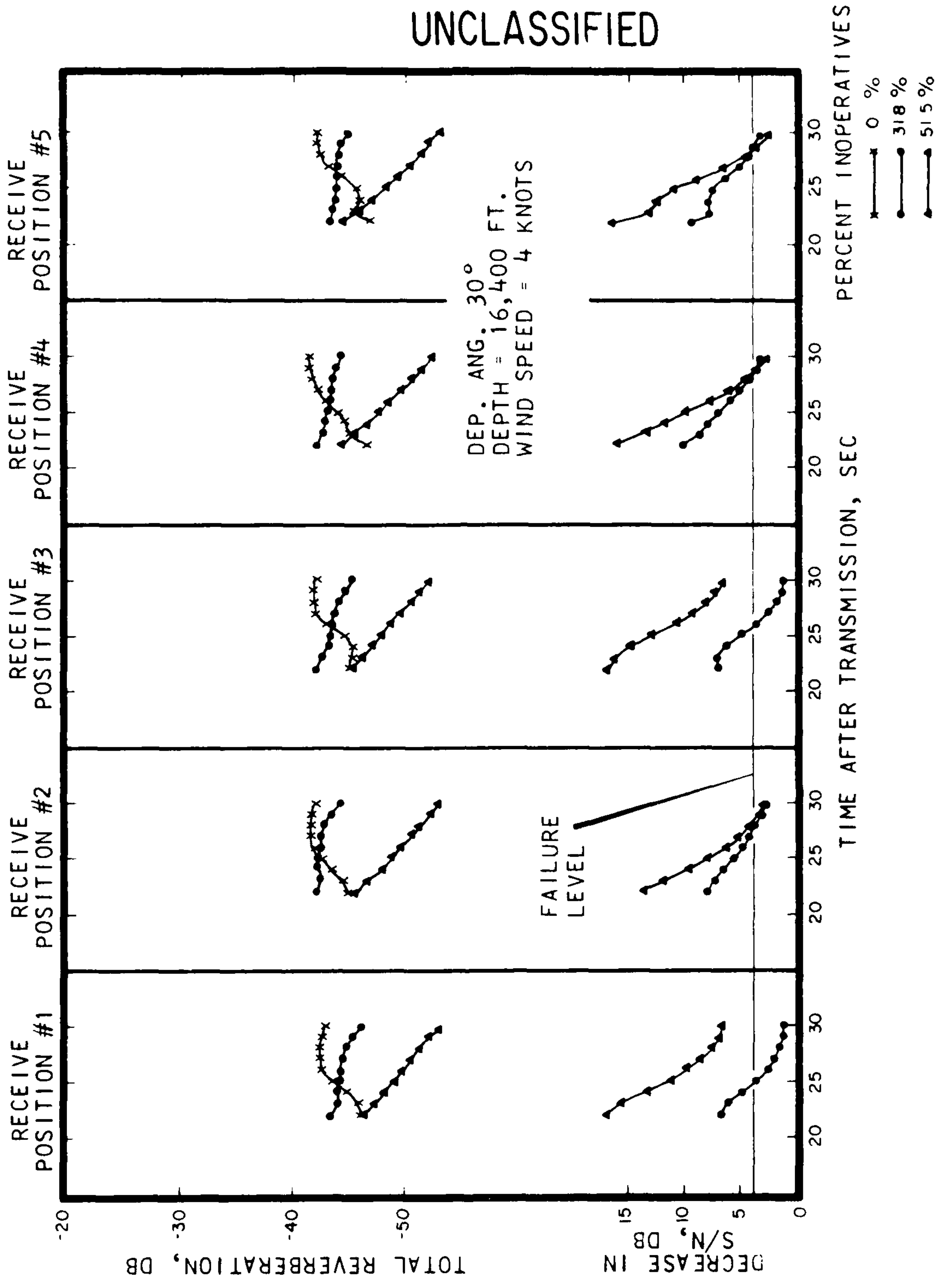

FIG. B-24 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR, INC DWG A6-13-2132
AUSTIN, TEXAS 5-16-67 McANALLY / S.D.

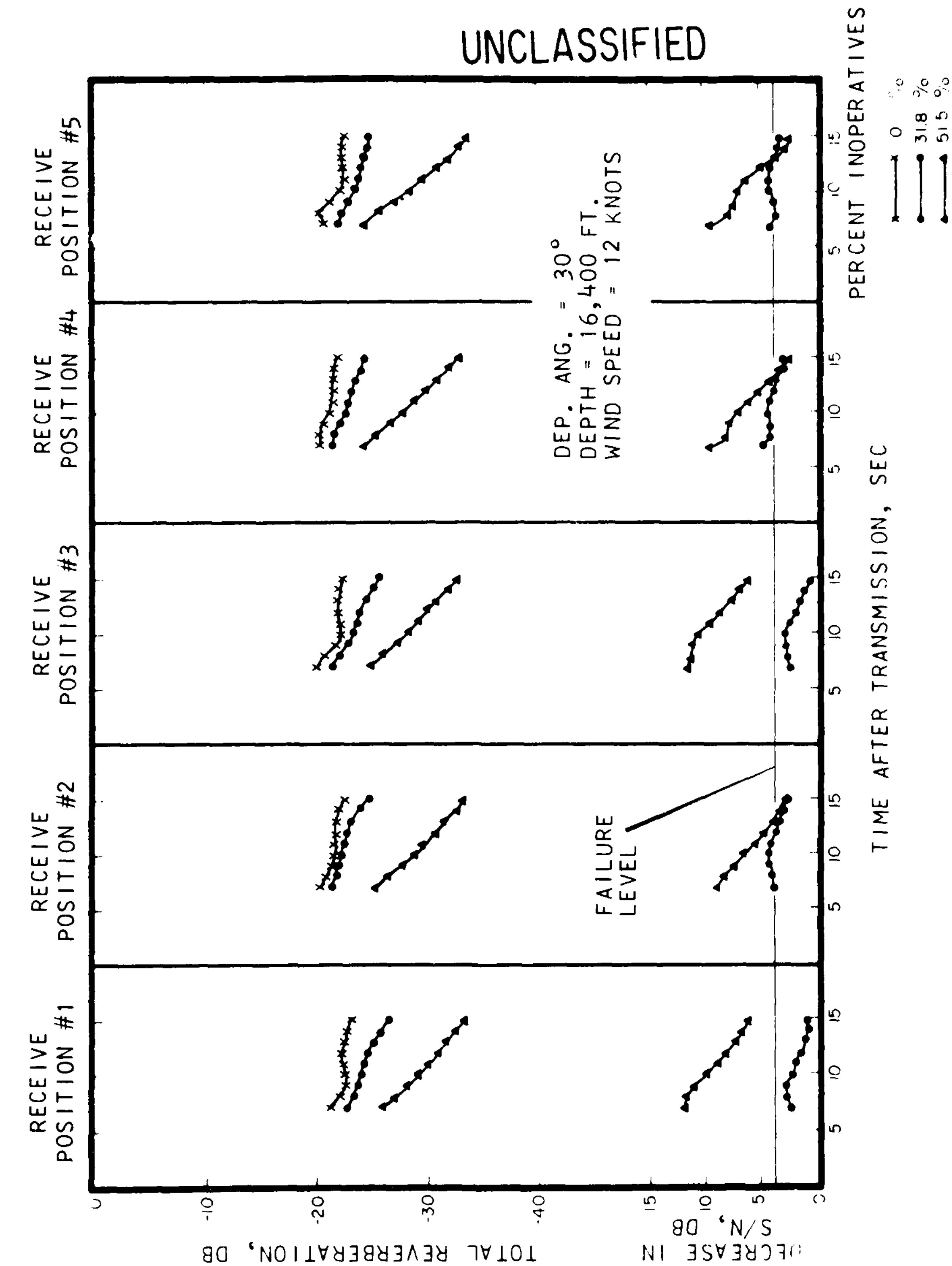

FIG. B-25 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

TRACOR INC
AUSTIN TEXAS 5-16-67 McANALLY/S.
DWG A6-13-213

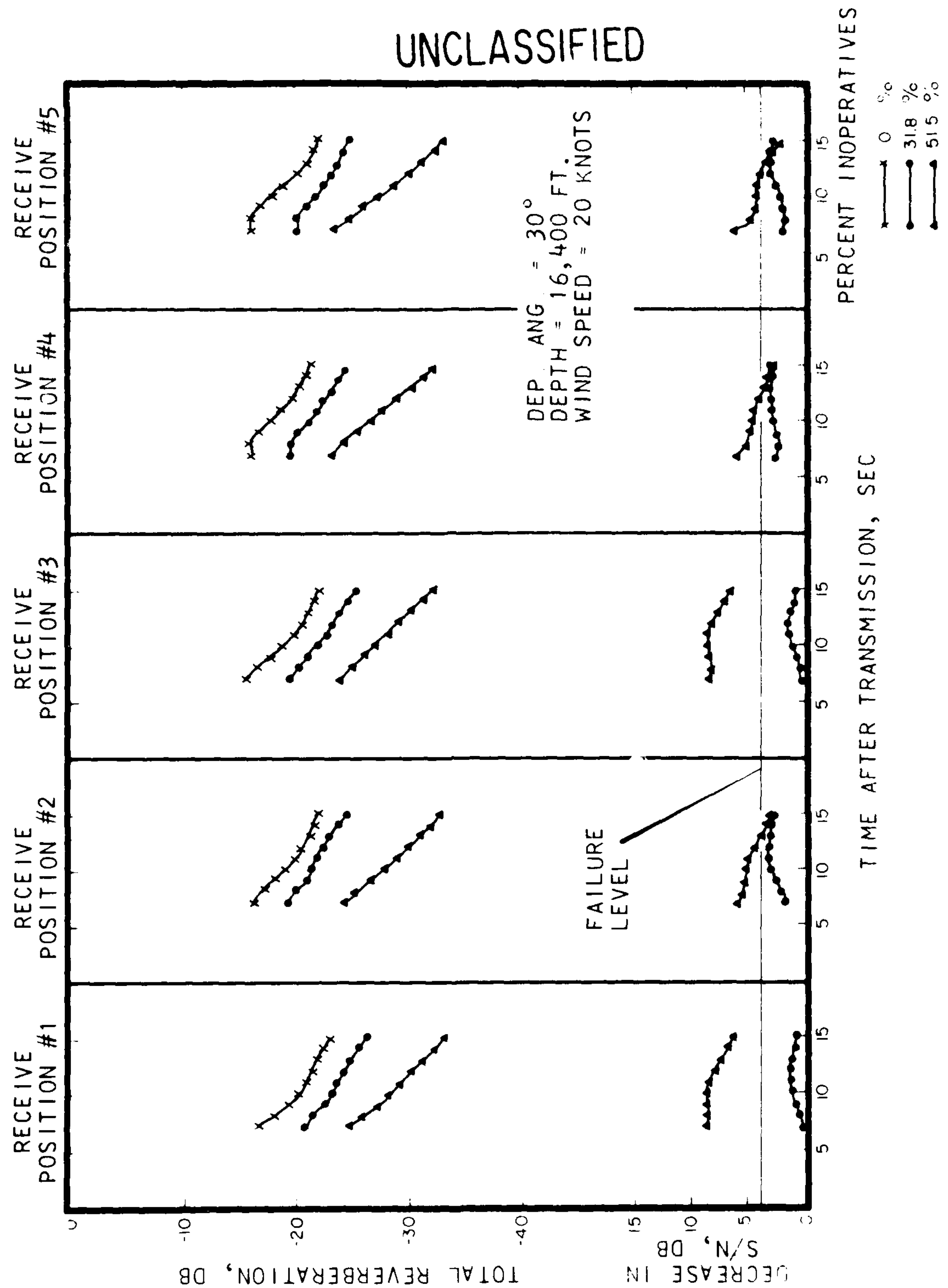

FIG. B-26 - TOTAL REVERBERATION LEVEL AND DECREASE IN S/N

DWG A6-13-
TEXAS 5-16-67 Mc ANALLY,

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Fig. A-18 CONTOUR PLOT FOR TRANSMIT BEAM PATTERN
20° DEPRESSION WITH 25% INOPERATIVES

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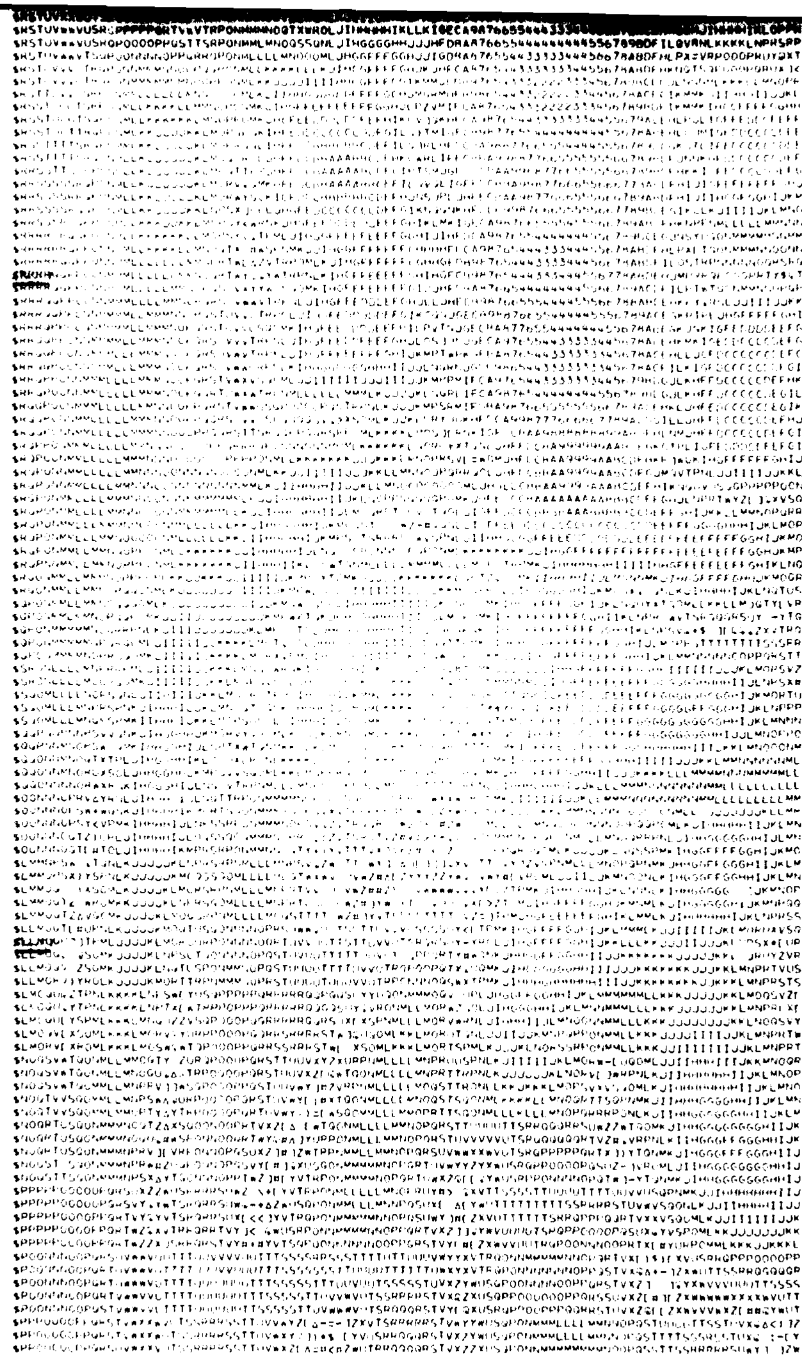

Fig. A-19 CONTOUR PLOT FOR TRANSMIT BEAM PATTERNS 20° DEPRESSION WITH 31.8% INOPERATIVES

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FIG. A-10 CONTOUR PLOT FOR TRANSMIT BEAM PATTERNS 20° DEPRESSION WITH 51.5% INOPERATIVES

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FIG. 5-21 CONTOUR PLOT FOR RECEIVE BEAM PATTERNS
DEPRESSION WITH OF INOPERATIVES

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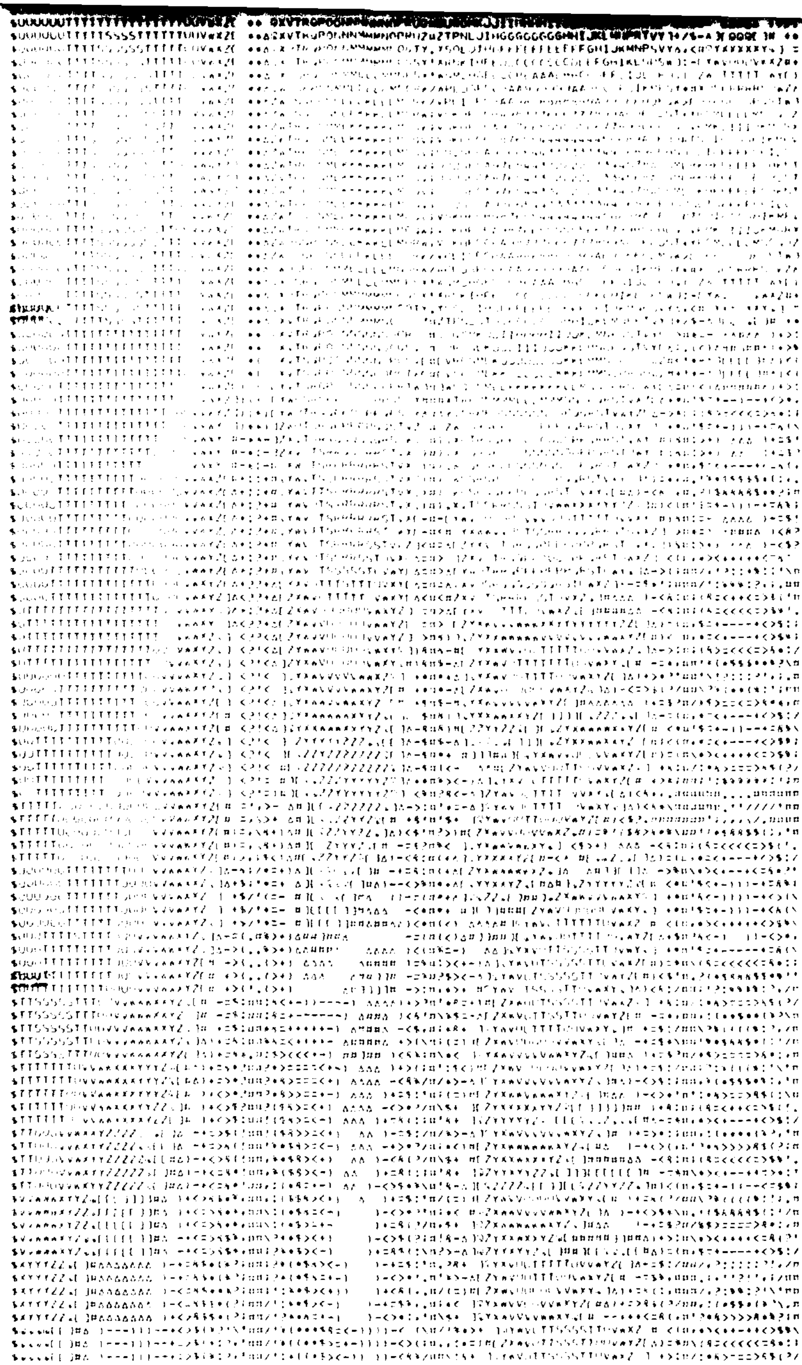

Fig. A-22 CONTOUR PLOT FOR RECEIVE BEAM PATTERN 20° DEPRESSION WITH 252 INOPERATIVES

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[illegible] CONTOUR PLOT FOR RECEIVE BEAM PATTERN
[illegible] DEPRESSION WITH [illegible] INOPERATIVES

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2

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Fig. A-24 CONTOUR PLOT FOR RECEIVE BEAM PATTERN 20° DEPRESSION WITH 51.5% INOPERATIVES

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Fig. A-25 CONTOUR PLOT FOR TRANSMIT BEAM PATTERN
30° DEPRESSION 0% INOPERATIVES

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Fig. A-26 CONTOUR PLOT FOR TRANSMIT BEAM PATTERN
30° DEPRESSION 31.8% INOPERATIVES

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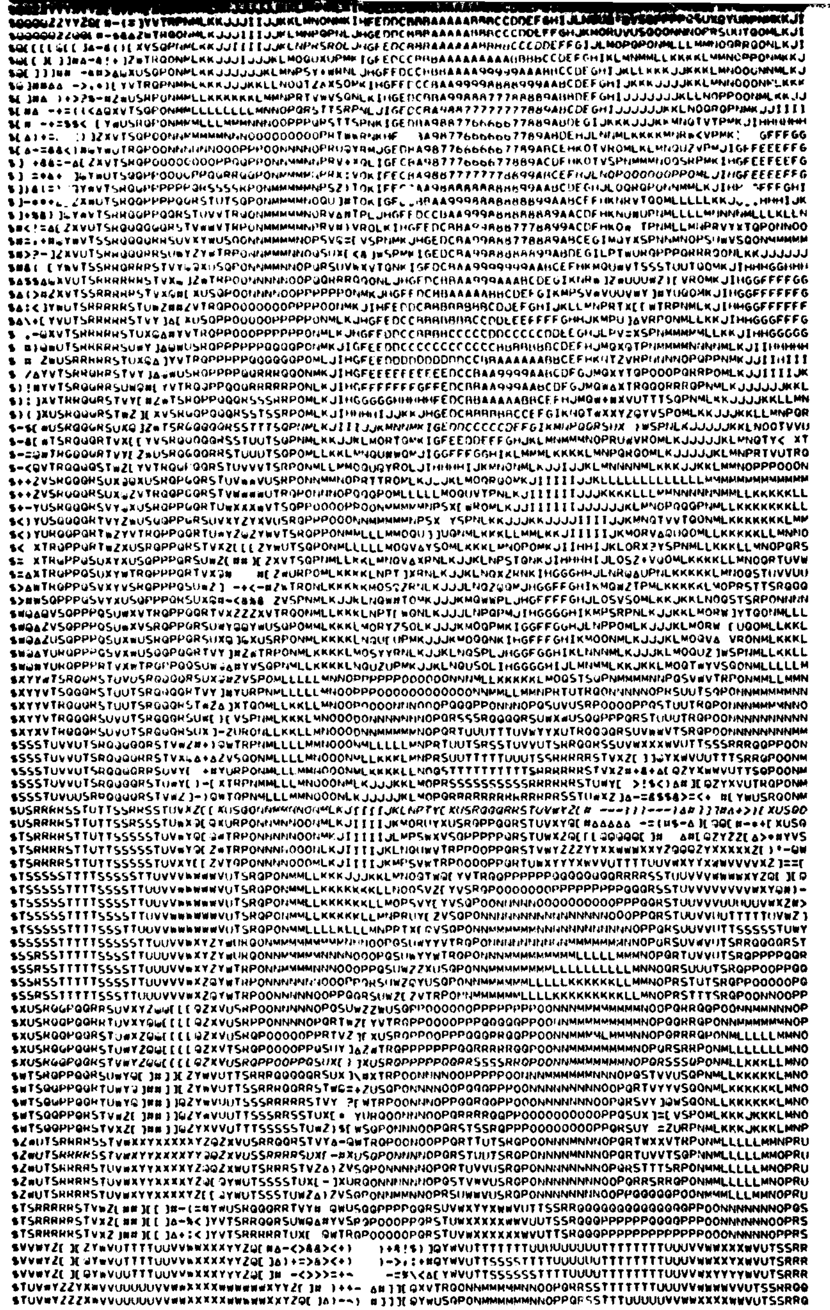

Fig. A-27 CONTOUR PLOT FOR TRANSMIT BEAM PATTERN
30° DEPRESSION 51.5% INOPERATIVES

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Fig. A-28 CONTOUR PLOT FOR RECEIVE BEAM PATTERN
30° DEPRESSION 0% INOPERATIVES

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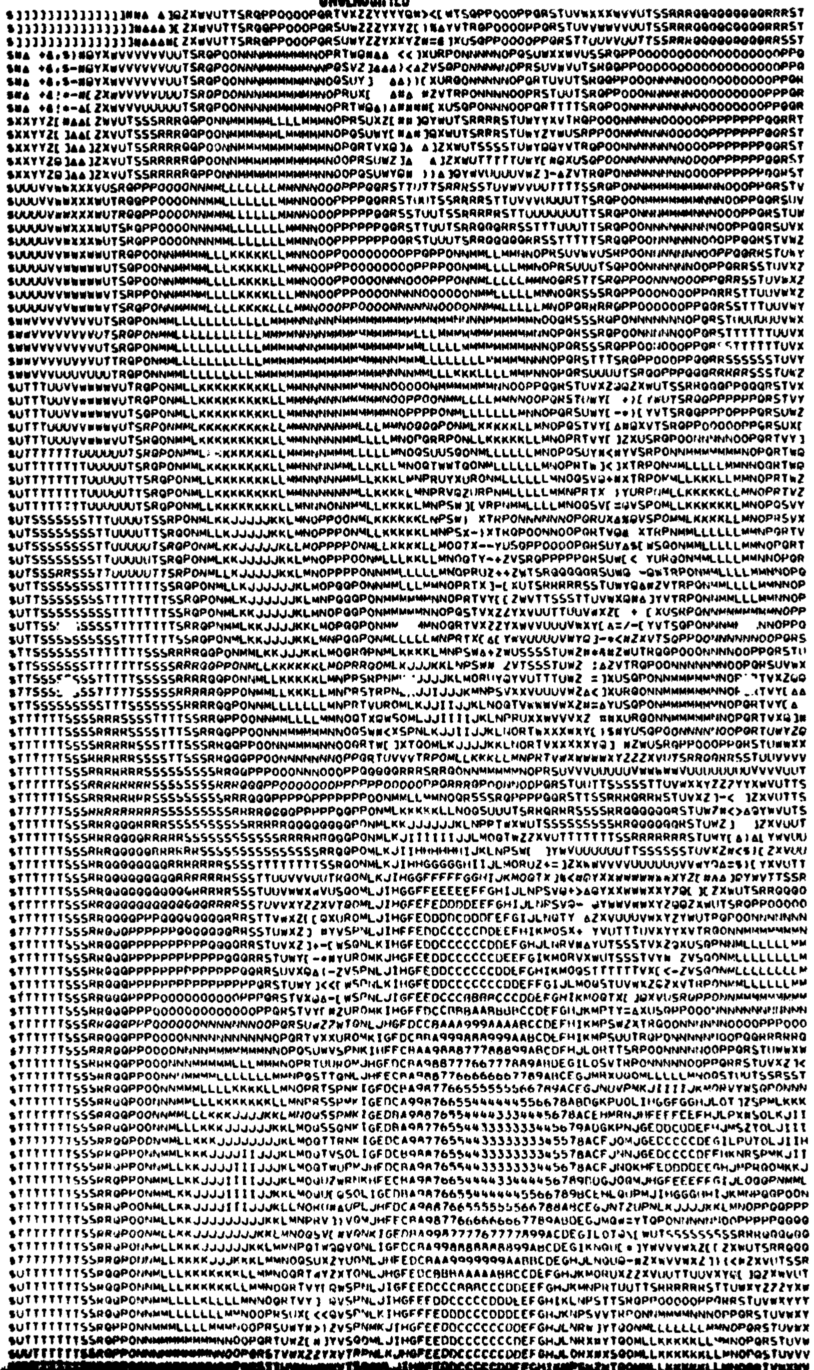

Fig. A-29 CONTOUR PLOT FOR RECEIVE BEAM PATTERN
30° DEPRESSION 31.8% INOPERATIVES

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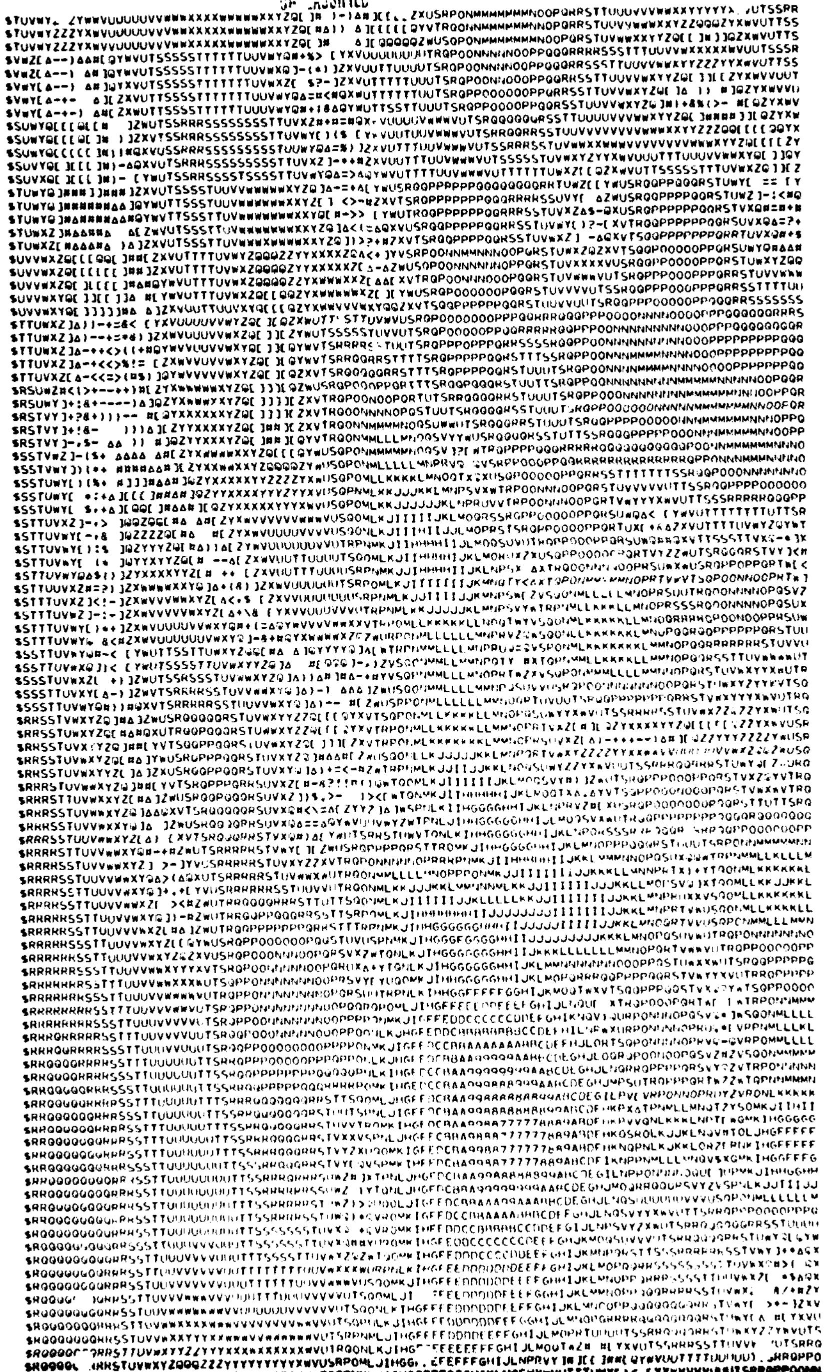

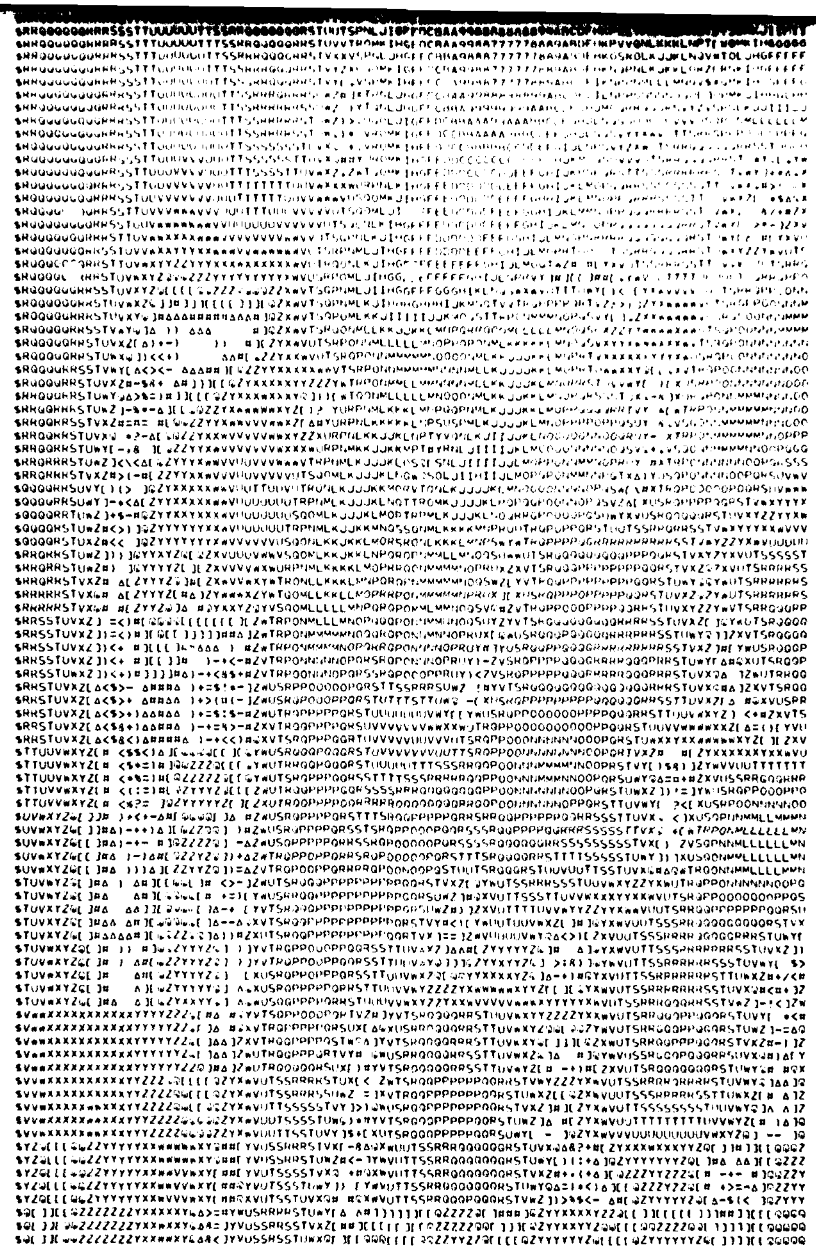

Fig. A-30 CONTOUR PLOT FOR RECEIVE BEAM PATTERN
30° DEPRESSION 51.5% INOPERATIVES

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3. REPORT TITLE

Detrimental Effects of High Side Lobes in a Reverberation Field(U)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Memorandum

5. AUTHOR(S) (Last name, first name, initial)

McAnnally, Michael A.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
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8a. CONTRACT OR GRANT NO. NObsr-95149 b. PROJECT NO. SS041-001 c. Task 8100 d.	9a. ORIGINATOR'S REPORT NUMBER(S) TRACOR 67-383-C 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Ship Systems Command Washington, D. C. Code 1631

13. ABSTRACT

The AN/SQS-26 sonar system is analyzed after failure of certain elements to determine if signal loss caused by decreased beam pattern response, and noise level change caused by reverberation level change are sufficient to declare a system failure. A system failure criterion is established in terms of the change in the output signal-to-noise ratio (S/N) from the beamformer. The input (S/N) of a properly operating sonar is considered as the reference, and the decrease in (S/N) caused by element failures is presented.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Sonar System Analysis						
Sonar Radiation Patterns						
Sonar System Failures						
Sonar Radiation Side Lobes						
Sonar Noise and Reverberation						

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